Environment Canada Environnement Canada
0050393J DEST PVM EXCH COPY 03
TP 360 E5613
VOL ISS 149
ENFOR PROJECT C

ENFOR Project C-149

Advanced Feedstock Preparation System for Large-Scale Hog Fuel Boilers

by

INPROHEAT Industries Ltd.

Contractor's Final Report [1]
DSS Contract 41SS.KL229-0-4170

ENFOR Project C-149

Advanced Feedstock Preparation System for Large-Scale Hog Fuel Boilers

by

INPROHEAT Industries Ltd.

Contractor: INPROHEAT Industries Ltd.
680 Raymur Avenue
Vancouver, B.C.
V6A 2R1

Scientific Authority:

Mr. R.J. Neale
ENFOR Program Co-ordinator, Biomass Conversion
Canadian Forestry Service
Environment Canada
20th floor, Place Vincent Massey
Hull, Quebec
K1A 1G5

Technical Liaison Officer:

Dr. J.F.G. Mackay
Research Scientist, Energy from Wood Waste
FORINTEK Canada Corp.
Western Laboratory
6620 N.W. Marine Drive
Vancouver, B.C.
V6T 1X2

[1] This report has been reviewed by the Canadian Forestry Service and approved for distribution. Approval does not necessarily signify that the contents reflect the views and policies of the Canadian Forestry Service. Mention of trade names or commercial products does not constitute recommendation or endorsement for use.

November 1982

INPROHEAT

ABSTRACT

A specially designed probe was constructed to sample gases at the interface zone between solid fuel combustion and gas phase combustion above the grate of a hog fuel boiler. The gas was to be analyzed for a range of boiler operating conditions. Tests were performed and some results were obtained, however, the combustion zone conditions were too severe and variable to achieve the original objectives using the probe design chosen.

A pilot plant flash dryer was constructed to evaluate the feasibility of using boiler exhaust gases to reduce the moisture content of the product from a hog fuel rotary dryer. A suitable suspension firing product was produced.

Testing was conducted to specify some criteria for improving hog fuel preparation including pulverizing, densification and ash removal.

ACKNOWLEDGEMENT

The work described in this report would not have been possible without the co-operation of the staff of the Canadian White Pine Division of MacMillan Bloedel Ltd..

INPROHEAT

TABLE OF CONTENTS

		PAGE
ABSTRACT		i
ACKNOWLEDGEMENT		ii
1. INTRODUCTION		1
1.1	General	1
1.2	Objectives	1
2. PROBE		3
2.1	Objectives	3
2.2	Test Site	4
2.3	Probe Design	4
2.4	Preliminary Testing	5
2.4.1	Sample Conditioning	5
2.4.2	Test Procedure	6
2.4.3	Results	6
2.5	Final Testing	8
2.5.1	Procedure	8
2.5.2	Results	9
3. FLASH DRYER		12
3.1	Objectives	12
3.2	Background	12

		PAGE
3.3	Test Site	13
3.4	Design	13
3.4.1	Parameters	13
3.4.2	Components	14
3.4.3	Safety	16
3.5	Monitoring	17
3.5.1	General	17
3.5.2	Temperature Measurement	17
3.5.3	Pressure and Flow	17
3.5.4	Moisture Content	18
3.5.5	Mass Flow	18
3.5.6	Size Distribution	19
3.5.7	Gas Analysis	19
3.6	Testing Program	19
3.6.1	Procedure	19
3.6.2	Accuracy	20
3.6.3	Input Fuels	21
3.6.4	Pulverizer Screen	21
3.7	Testing Program Results	21
3.7.1	Test Runs	21
3.7.2	Size Classifier	24
3.7.3	Effect of Feedstock Infeed Rate	25
3.7.4	Effect of Stack Gas Velocity	26
3.7.5	Effect of Stack Gas Temperature	26

		PAGE
3.7.6	Assessment of Drying Performance	26
4.	FEEDSTOCK PREPARATION	28
4.1	Pulverization	28
4.2	Densification	28
4.3	Ash Removal	29
5.	CONCLUSIONS AND RECOMMENDATIONS	32

FIGURES

FIGURE 1	Combustion Zone Probe Schematic
FIGURE 2	Combustion Zone Probe Inserted into Boiler No. 3 at Canadian White Pine
FIGURE 3	Probe Sampling Combustion Zone Gases
FIGURE 4	Fluctuations of Furnace Carbon Dioxide Readings Prior to the Sample Conditioning Package
FIGURE 5	Typical Hog Fuel for Boiler Probe Tests
FIGURE 6	Carbon Dioxide Profile for Combustion Zone Test
FIGURE 7	Carbon Monoxide Profile for Combustion Zone Test
FIGURE 8	Variation of Carbon Monoxide and Temperature with Height above the Fuel Bed
FIGURE 9	Pilot Plant Flow Schematic
FIGURE 10	Pilot Plant Elevation
FIGURE 11	Pilot Plant Plan

FIGURES

FIGURE I2	Flash Dryer Pilot Plant Located at Canadian White Pine
FIGURE I3	Flash Dryer Screw Conveyor and Inlet Hopper
FIGURE I4	Pilot Plant Monitoring
FIGURE I5	Size Distribution for Typical Flash Dryer Infeeds
FIGURE I6	Variation in Particle Moisture Content for Flash Dryer Infeeds
FIGURE I7	Flash Dried Cedar Rotary Dryer Outfeed
FIGURE I8	Flash Dried Screened Cedar Fines
FIGURE I9	Variation of Output Product Size Distribution with Pulverizer Screen Size
FIGURE 20	Comparison of Flash Dryer Discharges for Different Pulverizer Discharge Screens
FIGURE 21	Test A - Full Temperature Profile for Cedar Rotary Dryer Outfeed
FIGURE 22	Test B - Full Temperature Profile for Screened Cedar Fines
FIGURE 23	Test A - Partial Temperature Profile for Cedar Rotary Dryer Outfeed
FIGURE 24	Test B - Partial Temperature Profile for Screened Cedar Fines
FIGURE 25	Comparison Between Oversize Discharge and Cyclone Discharge for Flash Dried Cedar Rotary Dryer Outfeed
FIGURE 26	Typical Size Variation Between Oversize Discharge and Flash Dryer Discharge
FIGURE 27	Variation of Flash Dryer Discharge Product Moisture Content with Infeed Flow
FIGURE 28	Variation of the Moisture Content of Flash Dried Screened Cedar Fines with Particle Size and Infeed Flow
FIGURE 29	Comparison of Flash Dried Product Passing Through Sieves of Different Sizes

FIGURES

FIGURE 30	Variation in Pulverizer Discharge Temperature with Flash Dryer Infeed Rate
FIGURE 31	Variation of Drying Rate with Flash Dryer Infeed
FIGURE 32	Variation of Water Evaporated with Rate of Infeed
FIGURE 33	Variation of Flash Dryer Product with Stack Gas Velocity
FIGURE 34	Variation of Drying Rate with Stack Gas Temperature
FIGURE 35	Pulverizing Record for C.W.P. Cyclone Catch
FIGURE 36	Pulverizing Record for Wood Fines
FIGURE 37	Densified Wood Samples

INPROHEAT

ADVANCED FEEDSTOCK PREPARATION SYSTEM FOR LARGE-SCALE HOG FUEL BOILERS

1. INTRODUCTION

1.1 General

This Final Report details work carried out under ENFOR contract C-149, from May 1980 to June 1982, entailing

- measurement of combustion zone parameters in a hog fuel boiler.
- development and testing of a pilot plant flash dryer.
- specification of criteria for feedstock preparation techniques which can be used to improve hog fuel boiler performance.

1.2 Objectives

The major objectives of the work described in this report were:

1. To measure combustion parameters (temperature, gas composition and particulate loading) for a range of operating conditions at the interface between solid fuel combustion and gas phase combustion above the grate of a relatively large scale hog fuel boiler.

2. To quantitatively relate fuel characteristics (moisture content and size distribution) to boiler performance (unit steaming capacity, control response, efficiency and stack emissions).

3. To evaluate the feasibility of a secondary flash dryer for reducing the moisture content of the product from a rotary dryer and to optimize design parameters, including inlet and outlet temperatures, velocity, length and configuration.

4. To specify some criteria for improving hog fuel preparation including:

   - pulverizing
   - densification of intermediate fuel fraction
   - ash removal from suspension firing fuel

2. PROBE

2.1 Objectives

The main objective of the test program was to gain a clearer understanding of the results of changing input conditions on boiler performance. It was hoped that the data collected and analyzed would be useful in improving boiler control strategies and combustion air delivery systems as well as gain a clearer understanding of the effects of hog fuel drying.

The specially designed probe was to sample the gases present at the interface zone during typical boiler operation. The gas samples were to be collected in standard gas sample bottles for later analysis by a gas chromatograph.

The tests were to be conducted for a range of boiler operating conditions and would provide useful design information. For example, if the ratio of underfire to overfire air was altered, measurable changes in combustion should occur. Also, combustion efficiency and boiler efficiency would doubtlessly change.

Samples of feedstock were to be taken and analyzed for size distribution and moisture content. The effect of feedstock characteristics on combustion zone gases was to be determined.

2.2 Test Site

Probe testing was conducted on Boiler #3 at Canadian White Pine (C.W.P.).

Boiler #3 is a balanced draft Riley Type RX spreader stoker boiler, installed in 1955. The capacity is 36,000 kilograms per hour of steam at a design pressure of 1700 kilopascals. The furnace grate is a pinhole type approximately 3.9 meters long by 4.8 meters wide.

The boiler is predominantly fired on hog fuel, produced on site, but can be fired on any required combination of natural gas and hog fuel. Hog fuel is supplied to the furnace by four pneumatic feeders. A portion of the hog fuel is dried in a rotary dryer to a nominal 30 percent wet basis (w.b.) moisture content. This is blended prior to grate distribution with wet hog of about 55 percent moisture content (w.b.).

2.3 Probe Design

A modified ash removal door was fitted with an adjustable bearing sleeve. The probe was designed to slide in the sleeve through the door observation port. The modified door was positionable at any of the four ash removal door locations on the furnace. The adjustable sleeve was intended to allow easy lengthwise or angular probe positioning.

The probe (Figure 1) was designed to traverse the central 2.8 meters of the boilers' 3.9 m overall length and could be tilted a maximum of 15 degrees above horizontal. This allowed for maximum testing height of about one meter above the grate at the furthest probe insertion point. The central zone was chosen rather than the entire length to limit water wall effects on sampling. In addition, fuel dispersion was more even over the central part of the boiler.

Gas samples were drawn through a tube running lengthwise along the probe central axis. This gas sampling tube was covered by an insulated and electrically heated jacket. This jacket was surrounded by a tube bundle. Two tubes in the bundle contained thermocouple wires and another was used for measuring the stagnation pressure in the furnace. The remaining tubes were used for carrying cooling water from the water inlet to the gas sampling end of the probe. At this point the water exited the tubes and returned to the water outlet on the outside of the tube bundle.

2.4 Preliminary Testing

2.4.1 Sample conditioning

The procedure to be followed involved drawing the gas sample through the probe and then through a gas sample conditioning train (Figures 2, 3).

The conditioning train consisted of a heated length of hose which was connected to the end of the probe and then to a standard Joy-Western Precipitation stack sample box. The sample train comprised a heated and insulated gas sample bottle, heated particulate filter, and a set of water/ice chilled impingers. From the impingers the gas flowed to a second unit which contained a vacuum pump to draw the sample through the probe and sample conditioning box.

2.4.2 Test Procedure

The intended test procedure involved taking a coarse gas and temperature profile of the furnace and observing changes in the gas samples as the boiler operating conditions were changed. The probe was to be inserted in each door at two equidistant horizontal locations. At each location a sample was to also be taken at a higher elevation. This would result in 16 gas samples being taken for each test series.

Each gas sample test would start when probe conditions (water flow and temperature) were stable. The gas sampling train would be connected to the probe and a sample drawn for 15 minutes. During this time particulate, condensible hydrocarbons and condensed water were to be collected. Also combustion zone temperatures, stagnation pressures and boiler conditions were to be logged. At the end of the sampling period the valves on the gas sampling bottle would be closed and the bottle stored for later analyses. It was expected that between two and four gas series could be completed per day.

2.4.3 Results

During preliminary testing it became obvious that conditions in the furnace were more severe and unstable than originally expected and several problems were encountered:

- Load swings made it impossible to obtain a complete series of meaningful readings at stable conditions. To move the probe to a new location and then take

a set of readings (gas composition, temperature and particulate) required 20 - 30 minutes. To do a coarse survey (8 points) over the entire grate required over three hours. At most the furnace remained stable for 15 - 20 minutes.

- Fuel was constantly and unevenly dispersed over the grate. This resulted in a very uneven, constantly changing bed. In addition pile burning reduced visibility and made it virtually impossible to judge the bed thickness and furnace conditions at most gas sampling locations.

- Higher than expected levels of glowing particulate were drawn through the probe. These burning particles were likely altering gas composition data by continuing the combustion process as the gas moved through the sampling train. In addition to constantly plugging filters and burning through gas train sampling lines, the particulate was also plugging the stagnation pressure tube resulting in poor reading repeatibility.

- The heated and insulated gas sampling tube in the probe was maintained at 260^{o} C by the electrical controller, however some hot spots developed resulting in insulation breakdown. This allowed the heater element to short through and burn through the grounded gas sampling tube. Water then leaked into the gas sampling line giving invalid results and eventually plugged the line.

- Furnace conditions changed so rapidly (Figure 4) that sampling over an extended time frame, was not considered meaningful. Continuous monitoring would likely provide more useful information.

- The surface of the probe continuously became coated with tars and particulate. This coating was very difficult to remove and the gradual build-up between tests made it increasingly difficult to slide the probe in its bearing sleeve.

2.5 Final Testing

2.5.1 Procedure

It was clear from the preliminary tests that several changes were required to the testing program:

- The bearing sleeve made it very difficult to slide the probe in and out of the furnace. It was therefore removed from the ash removal door and the probe was moved through an enlarged slot on the door.

- A complete furnace survey was not practical. A single grate location was selected to be the site above which all gas sampling would be done. The position selected was 2.3 meters inside the furnace and about 1.6 meters from the nearest water wall tubes. This location was selected because it was in the central portion of the furnace in an area where furnace conditions appeared to be most stable. This location also facilitated the quick vertical positioning of the probe for a continuous gas sampling

program involving testing at different heights above the fuel bed.

- A new gas sampling train was designed which included a better continuous gas cleaning section and more durable components to handle glowing particulate. To reduce the particulate carryover the new sampling train pulled gas at a lower velocity. This resulted in non-isokinetic gas sampling but substantially less particulate carryover and likely more valid gas analysis.

- The temperature of the gas sampling line was maintained below 150^{o} C. This reduced the chances of further insulation breakdown and tube burn-through, but did result in a higher probability of tar condensation and subsequent probe plugging.

- Conditions in the furnace changed so rapidly that a continuous monitoring program appeared more likely to provide useful information. This was accomplished by connecting either a portable electronic carbon dioxide or carbon monoxide meter to the sampling train output. The volume of gas coming from the sampling train could not accommodate both meters being connected at once and therefore they were alternated as required. Spot checks of oxygen were made using a portable fyrite analyzer.

2.5.2 Results

Shortly after beginning the final tests the central tube started to leak water. This could have been caused by

further insulation failure of the gas sample line or stresses caused by probe bending. However, whatever the cause it meant that the central gas sampling line could not be used. To enable sampling to continue, one of the two thermocouple tubes was converted to a gas sampling line. This tube was not heated and therefore condensation of tars and water were expected to occur rapidly. When the probe did plug it was cleared as best as possible by inserting a 0.5 cm rod through the probe. This did not completely clear the probe, but it did allow short tests to continue between pluggings. Eventually the time available between plugging became shorter and the stagnation test tube was used to draw the gas through. When it finally plugged, the test program ended.

For all of the probe tests the cedar fuel remained at a fairly constant 50 percent average moisture content (w.b.) with a size distribution as shown in Figure 5.

Although plugging of the gas sampling tube made testing difficult, some data were taken and certain observations were made:

- A typical carbon dioxide profile is shown (Figure 6). For this test the probe was about 12 centimeters above the fuel bed. Carbon dioxide fluctuated between 10 - 16 percent with temperatures remaining from 800 - 1100^{0} C. The carbon dioxide level rose and fell in synchronism with the temperature.

- A typical carbon monoxide profile is shown (Figure 7). For these tests the carbon monoxide level ranged from 3 - 6 percent with temperatures varying between 900 - 1100^{o} C. The carbon monoxide level rose and fell 180 degrees out of phase with the temperature.

- Several tests were conducted showing that the carbon monoxide level decreased as distance above the bed increased (Figure 8).

- Carbon dioxide levels increased with increasing distance above the grate.

- Carbon monoxide levels increased and carbon dioxide levels decreased as the ratio of underfire/overfire was lowered. The carbon monoxide levels approached 19 percent as the underfire air was closed.

3. FLASH DRYER

3.1 Objectives

The purpose of constructing a flash dryer pilot plant was to develop an integrated system to prepare fine fuel suitable for overfiring in suspension in conventional hog fuel boilers.

The pilot plant testing program was intended to yield information which would be helpful in evaluating the feasibility of a secondary flash dryer for reducing the moisture content of the fines fraction of the product from a rotary dryer. In addition it was to provide information useful in optimizing design parameters including inlet and outlet temperatures, velocity, length, and configuration.

3.2 Background

The required characteristics of suspension firing fuel vary according to the source quoted. For the purposes of this report they are defined as a wood product with a moisture content of less than 15 percent (w.b.) and sized such that a sieve analysis produces essentially 100 percent less than 1.68 mm and 50 percent less than 0.84 mm.

Suspension firing quality fuel, because of its small particle size and low moisture content, behaves more like

a conventional fossil fuel. This results in better boiler control through higher turndown ratios and quicker response capability to changing load demands. In addition the higher quality fuel allows higher heat release rates than with grate fired fuel. Combustible particulate emission levels are in general lower with the suspension firing because of more thorough combustion. In part, this is because undergrate air is not required.

3.3 Test Site

The pilot plant was installed at C.W.P. and utilized boilerhouse stack gas as the primary heat source. The fuel to be dried was primarily cedar supplied by C.W.P. as a normal byproduct of their lumber operations.

One type was a typical hog fuel which had been partially dried in C.W.P.'s rotary dryer. The second was a higher moisture content product with a more uniform and smaller average particle size.

3.4 Design

3.4.1 Parameters

To simulate conditions which would be present in a commercial installation it was decided not to artificially control either the fuel characteristics or the stack gas conditions. Both were to be used as-received for each test.

The pilot plant was designed to accept a maximum of 1000 kg on an as-received basis of waste wood per hour. The primary source of this wood was the abort gate of the rotary dryer discharge conveyor. A second source of fuel was an overhead bin where screened material was stored. This later material had a nominal particle size of less than 5 mm and a 50 percent (w.b.) moisture content. Both of these wood products were known to have moisture contents and physical characteristics which would vary from test to test as well as during each test.

Stack gases from the boilerhouse were known to be variable to maximum temperature of 300^{o} C. A range of temperatures above 100^{o} C were to be tested.

The pilot plant discharge product was to be suitable for suspension firing using existing burner technology. This required producing a fuel where the majority of particles are less than 1.5 mm in size and also less than 15 percent (w.b.) moisture content.

3.4.2 Components

As shown on the flow schematic (Figure 9), associated plan and elevation views (Figures 10, 11), and accompanying photographs (Figures 12, 13) the final pilot plant design consisted of:

1. A 1 m^3 hopper and variable speed (0-1000 kg/hr) screw conveyor to deliver fuel to the pulverizer;

2. A 30 kW full circle pulverizer (hammermill), with interchangeable discharge screens, capable of grinding the input fuel to produce a product with the required size distribution;

3. An induced draft (I.D.) fan close coupled to the pulverizer to deliver the ground fuel and a variable amount of stack gas (up to 1.2 kg/s) through the 0.05 m^2 discharge ductwork at a minimum velocity of 15 m/s;

4. A forced draft (F.D.) fan and associated ductwork to deliver stack gas from the discharge breaching of #7 boilerhouse stack I.D. fan to the pulverizer intake. Initially stack gas was drawn through the pilot plant solely by the pulverizer I.D. fan. However, preliminary testing indicated significant amounts of ambient air were being pulled into the system. This air which was coming up the intake screw as well as through the pulverizer, significantly reduced the temperature of the drying gas. Complete sealing of air leaks was deemed impractical and therefore a second fan (flash dryer F.D. fan) was installed to pressurize the pulverizer and reduce the infiltration air;

5. A size classifier and rotary air lock to return oversize particles to the pulverizer for further size reduction. The size classifier consisted of an expanded ductwork section 3 meters long where the velocity of the larger particles would be slowed below their settling velocity (about 8 m/s).

6. A sampling cyclone was designed to remove the dried product from the gas stream for either sampling or direct discharge to C.W.P.'s No. 34 conveyor. The discharge gas along with the cyclone solids bypass was returned to the inlet breaching of No. 7 I.D. fan;

7. Associated ductwork and support steel. For ease of modification all ductwork and components were left uninsulated;

8. Required controls, valves, instrumentation, etc., to complete the pilot plant.

3.4.3 Safety

In any system where wood dust is being handled certain safety precautions are required to reduce the likelihood of fires and explosions. This is particularly true for a wood grinding operation. Although the pilot plant utilized stack gases with a reduced oxygen content which decreased these dangers, other precautions were needed to further lower the probability of an explosion.

A spark detection and suppression system was installed. The detector was located immediately after the pulverizer I.D. fan and an extinguishing spray was located about 10 meters downstream of this point. In addition, explosion vents were located on the cyclone and size classifier. During the test program a spark was detected on two occasions. The extinguishing spray triggered both times. After each triggering of the extinguishing spray, further problems were not evident.

3.5 Monitoring

3.5.1 General

The main purpose of the monitoring (Figure 14) was to provide data to qualitatively assess the pilot plant drying performance under known test conditions. To accomplish this required that an energy balance for the system be done.

The equipment selected was sufficiently simple, rugged and accurate to perform adequately in the outside, industrial, environment present.

3.5.2 Temperature Measurement

A multipoint millivolt chart recorder was connected to thermocouples located throughout the pilot plant. All temperatures were one point measurements taken at a position where average conditions were present.

3.5.3 Pressure and Flow

Pipe pressure taps were installed at several duct locations.

Elbow pressure taps were installed at selected locations to give indications of changing flow conditions during tests. When an accurate measurement of actual duct flow was required a standard pitot traverse of the duct was taken.

Pipe and elbow pressure taps were connected to standard pressure gauges located at a central panel. Both sets of these readings were used only to provide an indication of changing conditions which could be affecting pilot plant performance.

3.5.4 Moisture Content

Random grab samples of fuels to be flash dried were taken and oven-dried to obtain moisture contents.

3.5.5 Mass Flow

Feedstock inlet mass flow measurements were made by calibrating the infeed screw. The variable nature of the infeed wood meant that this value was only an estimate.

Timed samples of the flash dried product were also taken and weighed. However, cyclone losses had to be taken into account when this value was used. Estimates of the average cyclone losses were made by running weighed quantities of product through the flash drier and weighing the output product. Corrections for moisture contents were made and average efficiencies calculated.

Comparisons between the infeed values and the corrected outfeed values were made to arrive at the estimated bone dry product mass flows.

3.5.6 Size Distribution

Random samples of infeed and outfeed wood samples were oven-dried and then analyzed using a portable sieve shaker.

3.5.7 Gas Analysis

Random samples of the input stack gas oxygen and carbon dioxide content were taken using portable Fyrite testing apparatus. Random samples were also taken of the pulverizer discharge gas to check for air infiltration.

3.6 Testing Program

3.6.1 Procedure

After the preliminary testing stage was completed a final testing program and procedure was adopted.

Included in this procedure were:

1. Two types of cedar fuel were tested. One type a "cedar rotary dryer outfeed", and the other a "screened cedar fines".

2. A cyclone efficiency test was performed for each wood type at several operating conditions.

3. Grab samples of infeed wood were taken from the infeed hopper and analyzed for moisture content and size distribution.

4. Flash drying tests were started after relatively stable stack gas temperatures were reached.

5. All tests were conducted using a 1.98 mm pulverizer screen except for specific tests to show the change in particle size distribution for varying pulverizer screens.

6. Grab samples of outfeed wood were taken when the pulverizer outlet temperature had stabilized. Samples were sealed and analyzed for moisture content and size distribution.

7. Dampers were adjusted for each test to distribute the stack gas so that about one-half came in with the infeed through the pulverizer top and about one-half came in below the pulverizer screen.

8. All tests were conducted with the F.D. fan adjusted to slightly pressurize the pulverizer inlet plenum.

9. All tests were conducted at the maximum stack gas flow rate with the exception of the specific tests to show the effect of stack gas velocity on drying rate.

10. Spot-check pitot traverse measurements of pulverizer discharge velocities were taken for each test.

3.6.2 Accuracy

All measurements made and samples taken provide grab-type/

spot-check information. Input feed, output product, and stack gas characteristics fluctuated during the individual tests. These fluctuations were never greater than 10 percent for any individual test.

3.6.3 Input Fuels

The results presented are a summary of the flash dryer pilot plant performance for two types of infeeds. Most tests were run with cedar because it was the usual infeed at C.W.P. Typical size distribution (Figure 15) and moisture content (Figure 16) profiles are presented as well as photographs showing typical infeed and flash dried product (Figures 17, 18).

3.6.4 Pulverizer Screen

Three different sizes of pulverizer screens were used for controlling the output product size. A typical product size distribution profile for each screen is presented as well as photographs showing the typical flash dried product for each screen (Figures 19, 20). The profiles do not account for cyclone losses which should be less than 0.2 mm in size. The most significant particle size variation between the screens occurs in the mid-range below 0.84 mm screen size. There is thirty percent less material below this sieve size for the large diameter pulverizer screen.

3.7 Testing Program Results

3.7.1 Test Runs

Temperature profiles for typical tests with each infeed

wood type are presented (Figures 21, 22). Also included is a partial temperature profile for the same tests (Figures 23, 24) where only certain key temperatures are included. These temperatures are:

- T1 is a record of the stack gas temperature at the inlet to the pilot plant F.D. fan. It indicates the changing conditions of the boilerhouse exhaust gases and consequently the degree of stability of the pilot plant heat source.

- T2 is a record of the stack gas temperature at the upper inlet to the pulverizer. It provides an indication of air infiltration and ductwork heat losses prior to the pulverizer.

- T4 is a record of the gas stream temperature at the discharge of the pulverizer F.D. fan. Before the infeed wood is added it provides information about air infiltration and pulverizer heat losses to the surrounding environment. When wood is added it provides information on the heat transfer in the pulverizer between the stack gases and infeed wood. This indicates the amount of drying which occurs in the pulverizer and I.D. fan.

- T10 is a record of the gas stream temperature at the discharge of the cyclone. Before wood is added it provides details about the ductwork heat losses to the surrounding environment between the pulverizer

discharge and the cyclone. After wood is added it indicates the amount of heat transfer occuring between the gas stream and ground wood in the discharge duct-work. This indicates the amount of drying which occurs after the pulverizer.

For these tests the infeed rate was varied stepwise from zero to the maximum which the pilot plant would accept. Temperature differences between adjacent profiles are noted on the partial profiles.

Figures 23 and 24 detail the temperature record for these tests. Several items are notable:

- T1 was much more variable in test A. This was due to feedstock feeding problems in the boilerhouse. Tests were performed only when T1 was relatively stable.

- T1 was hotter during test B. Test A had fewer boilers operating in the boiler plant.

- The difference (T1-T2) is relatively constant for each test. The difference is larger when T1 is higher indicating greater heat losses to the surroundings because of the hotter duct temperature.

- The differences (T1-T2, T2-T4, T4-T10) at zero infeed are due to heat losses and air infiltration. These differences at all other times vary with infeed and are due to heat transfer between the gas stream and wood as well as heat losses and air infiltration.

- The difference (T2-T4) increases as the wood infeed rate is increased.

- The difference (T2-T4) is significantly greater than (T4-T10) indicating most heat transfer occurs in the pulverizer and its I.D. fan. For Test B at 3.4 hours an energy analysis indicated that 90 percent of the water was evaporated prior to the product leaving the flash dryer I.D. fan. This pattern was similar for other tests.

3.7.2 Size Classifier

As previously described the size classifier was an expanded section of ductwork where the oversize particles would slow to below their settling velocities and return to the pulverizer for further size reduction.

The maximum oversize return was five percent of the infeed flow. This was due to:

- The maximum pulverizer discharge screen opening was 1.98 mm. This resulted in a very small average particle size and therefore few particles fell below their settling velocity.

- The gas stream expanded only to about 70% of the available area of the size classifier. Modification to the inlet nozzle of the classifier to further expand the gas stream was not required because of the small average particle size and good overall drying.

As expected, the material which was returned did have a

larger average particle size than the flash dryer discharge (Figure 25, 26).

3.7.3 Effect of Feedstock Infeed Rate

The rate of fuel infeed to the pulverizer was altered while maintaining an approximately constant stack gas temperature and pulverizer exit velocity. Several results are noted including:

- With a relatively stable heat input the moisture content of the flash dried product increased with increasing infeed rate (Figure 27).

- For each infeed rate the moisture content for different particle sizes falls within a relatively narrow band (Figure 28). For a size comparison a standard sieve run is presented (Figure 29).

- With a relatively stable heat input the pulverizer discharge temperature decreased with increasing infeed rate. For the same mass flow in the discharge, the temperature was lower for higher moisture content fuels (Figure 30).

- The drying rate (kg of water evaporated per bone dry kg of infeed per hour) decreased with increasing infeed rates. Also, the drying rate was higher and decreased more rapidly for the higher moisture content fuel (Figures 31, 32).

This indicates that water becomes more difficult to remove as the product becomes drier.

3.7.4 Effect of Stack Gas Velocity

The stack gas velocity was altered by closing the cyclone discharge damper for each infeed at a relatively constant stack gas temperature. The moisture content of the flash dried product decreased with increasing stack gas velocity (Figure 33).

3.7.5 Effect of Stack Gas Temperature

The stack gas temperature was variable as previously described. Data from several tests with different stack gas temperatures at the maximum infeed rate are plotted in Figure 34. The lowest stack gas temperature was a test when the boilerhouse was not operating and ambient air was used as the drying medium. This low value is primarily representative of the drying taking place because of the energy input from the pulverizer. The results indicate that the drying rate decreases with decreasing stack gas temperature and decreases with decreasing infeed moisture content.

3.7.6 Assessment of Drying Performance

An energy balance for Test B at 3.4 hours yielded the following:

Input (referenced to 16° C)

Dry Stack Gases (Q_1)	503,000 kJ/hr
Pulverizer	31,800 kJ/hr
Input Wood	0 kJ/hr
Total	534,800 kJ/hr

Output (referenced to 16° C)

Dry Stack Gases (Q_2)	148,900 kJ/hr
Output Wood	19,700 kJ/hr
Water Evaporated	291,400 kJ/hr
Losses (due to uninsulated ductwork)	74,800 kJ/hr
Total	534,800 kJ/hr

To evaporate one kilogram of water requires about 2,300 kJ of energy input. The actual energy input from the stack gases was 354,100 kJ/hr (Q_1 - Q_2) to evaporate 126.4 kg/hr of water. This gives a value of 2,800 kJ to evaporate one kilogram of water for the pilot plant. The losses are due mainly to the uninsulated ductwork. However, as previously mentioned, 90 percent of the drying occurred prior to the product leaving the flash dryer I.D. fan. Therefore the dryer efficiency would have been only marginally increased by insulating and/or lengthening the discharge ductwork.

4. Feedstock Preparation

4.1 Pulverization

Pulverizing tests were conducted using the cyclone catch from the discharge of the C.W.P. rotary dryer. This product had an average 15 percent moisture content (w.b.) and a size distribution as shown in Figure 35, (curve A). Using a 3.2 mm and a 1.6 mm pulverizer discharge screen the product produced is indicated in Figure 35, (curves B, C). The estimated energy consumption requirements to produce different product characteristics were:

- 100 percent minus 1.68 mm - 118 kJ per kg
- 100 percent minus 0.841 mm - 207 kJ per kg
- 100 percent minus 0.595 mm - 265 kJ per kg

This indicates that less than two percent of the heating value of bone dry wood (20000 kJ/kg) is required to produce a fine ground product (100 percent minus 0.595 mm).

Pulverizing tests were also conducted using wood fines with a 8 percent moisture content (w.b.). Using a 0.79 mm pulverizer discharge screen the energy usage was 29.6 kJ per kg to produce a very fine product (Figure 36).

4.2 Densification

Samples of the two infeeds used in the flash dryer pilot plant tests (Figures 15, 16) were densified using two types of production machines. The first machine produced a

cylindrical pellet (6 mm diameter by 20 mm long) and the second produced a larger briquette type (45 mm x 45 mm x variable length) product (Figure 37).

Both the infeeds were too moist to be pelletized without prior drying. They were dried to 11 percent moisture content (w.b.) before densification. The pellet mill produced a good pellet from the screened cedar fines infeed. However the rotary dryer outfeed required grinding to 100 percent passing a 4 mm screen. A good pellet was produced from this ground product. The density of the individual pellets was 950 kilograms per cubic meter. The storage density of the pellets was 600 kilograms per cubic meter. This compares with an original storage density of 150 kilograms per cubic meter for the dried product prior to densification. The energy consumption was 84 kilojoules per kilogram.

The briquette mill was tested using the same two infeeds without prior drying. However, both types of briquettes easily crumbled and therefore were unsuitable. A ground cedar product with a 10 percent moisture content (w.b.) was tested and produced a good briquette. The density of the individual briquettes was 1080 kilograms per cubic meter. The storage density of the briquettes was 560 kilograms per cubic meter. The storage density of the ground infeed was 140 kilograms per cubic meter. The energy consumption was 93 kilojoules per kilogram.

4.3 Ash Removal

The ash content of the C.W.P. feeds tested were from three to four percent of the dry wood weight. The inherent ash content of wood is usually less than one percent. The

remaining two to three percent was "outside" ash (primarily silica sand) collected during normal handling and processing.

Tests were conducted to determine the feasibility of removing the "outside" ash from the cyclone catch described in section 4.1 by using a gravity separator. The separator was a commercial piece of equipment essentially consisting of a vibrating porous table through which low pressure air is blown. Product is fed onto the table and the air fluidizes and stratifies the material according to the different terminal velocities. The heavier particles fall onto the table and are conveyed away. Light particles are lifted and conveyed in a different direction. Tests on products wetter than the cyclone catch with a wider (larger particles) size distribution were not deemed practical because:-

- pieces of sand cling tightly to wet wood. The surface tension of water in wetter feeds rapidly decreases the effectiveness of gravity separators.

- a wide size distribution results from trying to separate a large light particle (wood) from a small heavy particle (sand). This separation is not very successful using standard techniques.

It was not possible to run the complete cyclone catch sample. The smallest fraction (minus 0.5 mm sieve) impeded the operation of the gravity separator and had to be screened out. This represented 28 percent of the total sample. Tests on the remaining sample (plus 0.5 mm sieve) removed about 75 percent of its sand content. This sand was primarily between 0.21 and 0.84 mm in size.

The above tests indicate that a portion (about 50 percent) of the "outside" sand can be removed from the total sample using gravity separators. This would result in lowering

the hog fuel ash content to two to three percent of the dry wood weight.

Although this method is technically feasible it may not be commercially practical to do so except for a very stringent product requirement.

5. Conclusions and Recommendations

5.1 The combustion zone conditions in an operating industrial hog fuel boiler are too severe and variable to be successfully examined with the probe and methods described in this report. A more detailed study involving simultaneous, multipoint analysis of the combustion zone using an improved probe design is required.

5.2 It is possible to produce a suspension firing quality fuel using low temperature stack gases (to 150^{0} C) to dry pulverized wood of varying characteristics (moisture content and size distribution).

5.3 For the flash drying arrangement presented 90 percent of the drying occurs prior to the pulverizer I.D. fan discharge.

5.4 A degree of size classification is possible using a simple settling chamber. Indications are that a better classification can be obtained by making minor changes to the classifier.

5.5 Increasing the rate of feedstock infeed with a constant heat input:

- increases the moisture content of the flash dried product
- decreases the pulverizer exit temperature. This temperature is lower for higher moisture content fuels
- decreases the drying rate. The drying rate decreases more rapidly for higher moisture content fuels.

5.6 The moisture content of the flash dried product decreases with increasing stack gas velocity.

5.7 The drying rate decreases with decreasing stack gas temperature.

5.8 To produce a suspension firing quality fuel from the cyclone catch of the C.W.P. rotary dryer requires about 118 kJ per kg for the pulverizer.

5.9 The energy required to produce a pelletized product from cedar with a 11 percent moisture content (w.b.) is 84 kilojoules per kilogram. The energy required to produce a briquette product from cedar with a 10 percent moisture content is 93 kilojoules per kilogram.

5.10 Removing collected sand from fine wood product is technically feasible but may not be economically practical because the wood cannot be too wet or too small. Both of these restrictions must be considered when gravity separators are used.

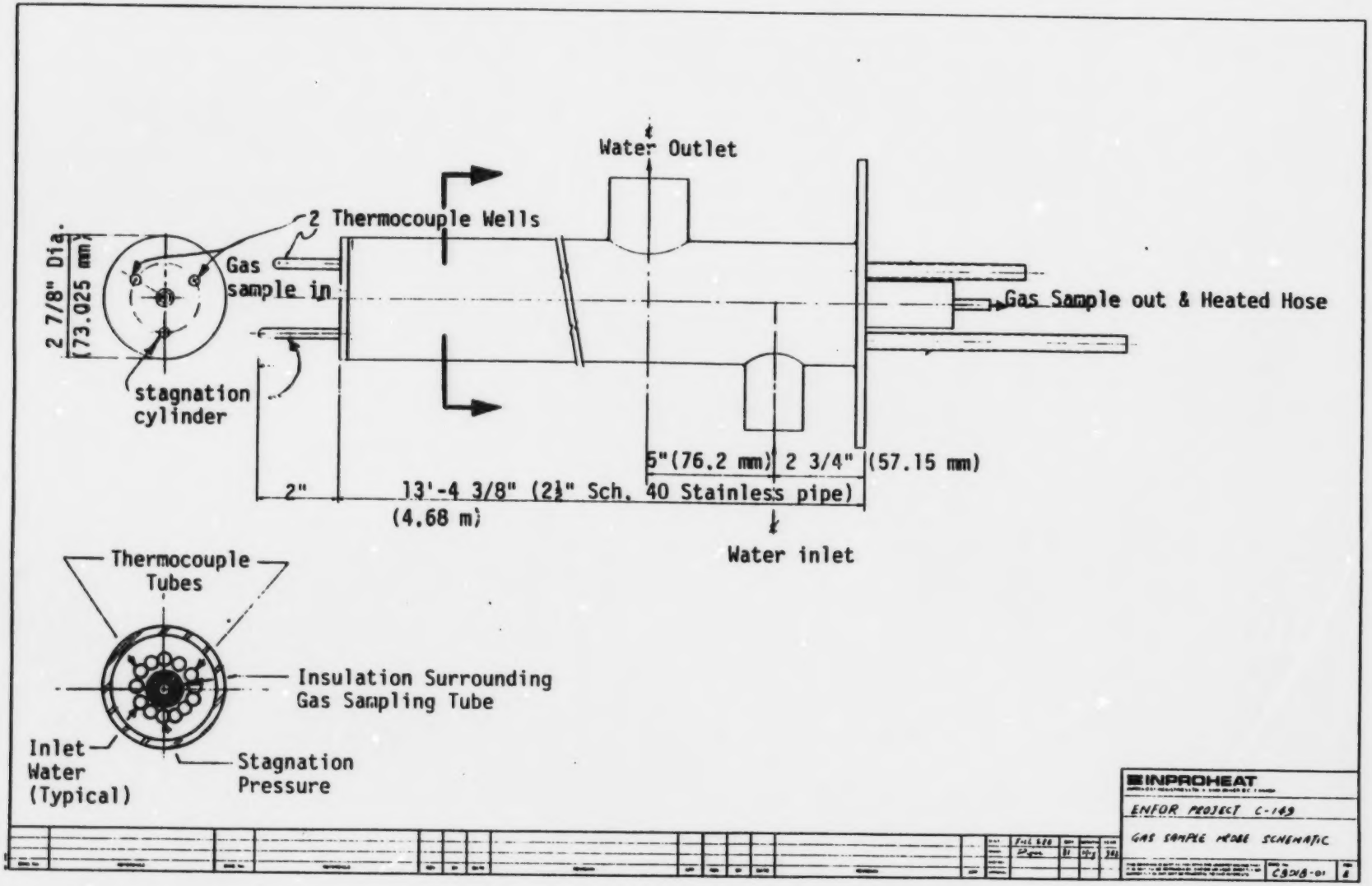
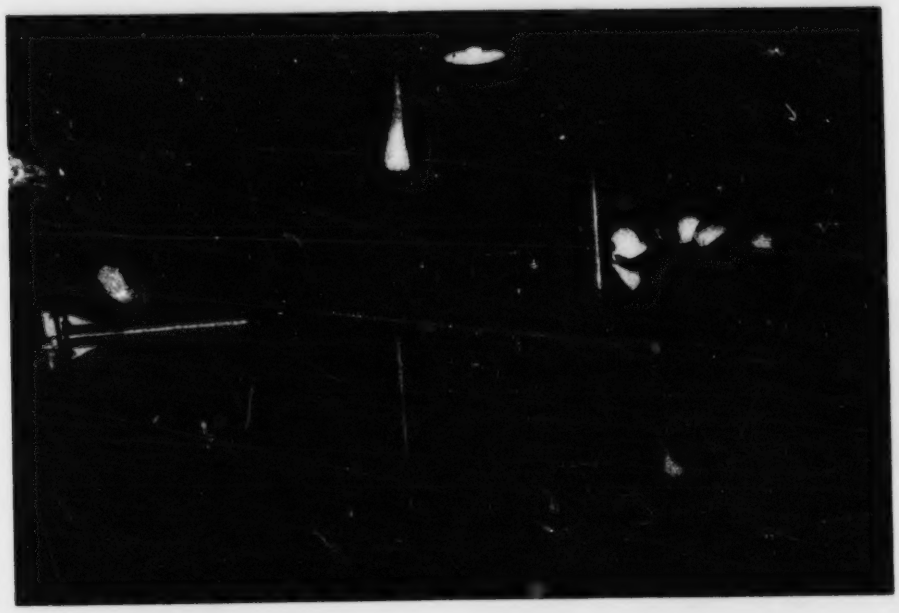


FIGURE 1: Combustion Zone Probe Schematic



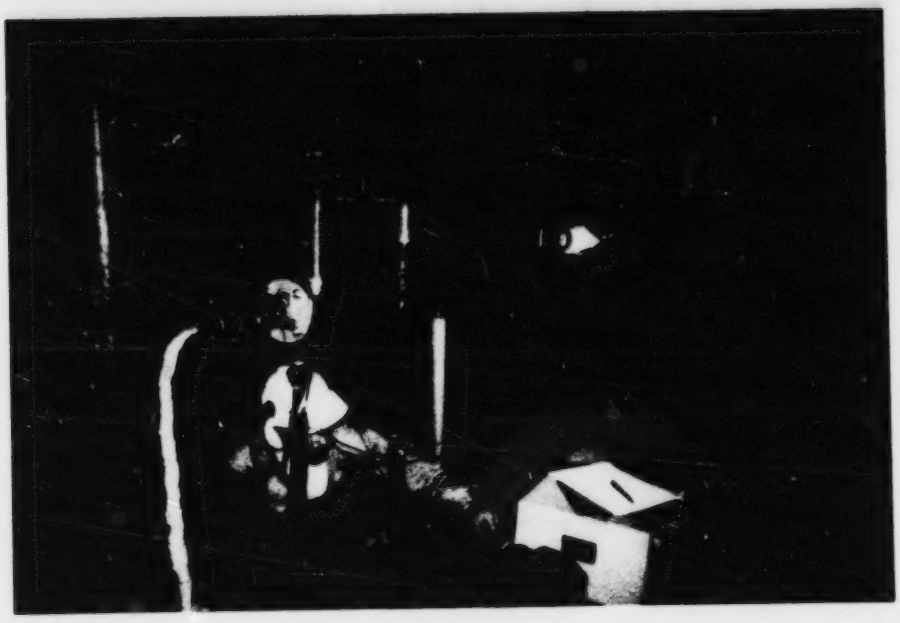


FIGURE 2: Combustion Zone Probe Inserted into Boiler No. 3 at Canadian White Pine

FIGURE 3: Probe Sampling Combustion Zone Gases

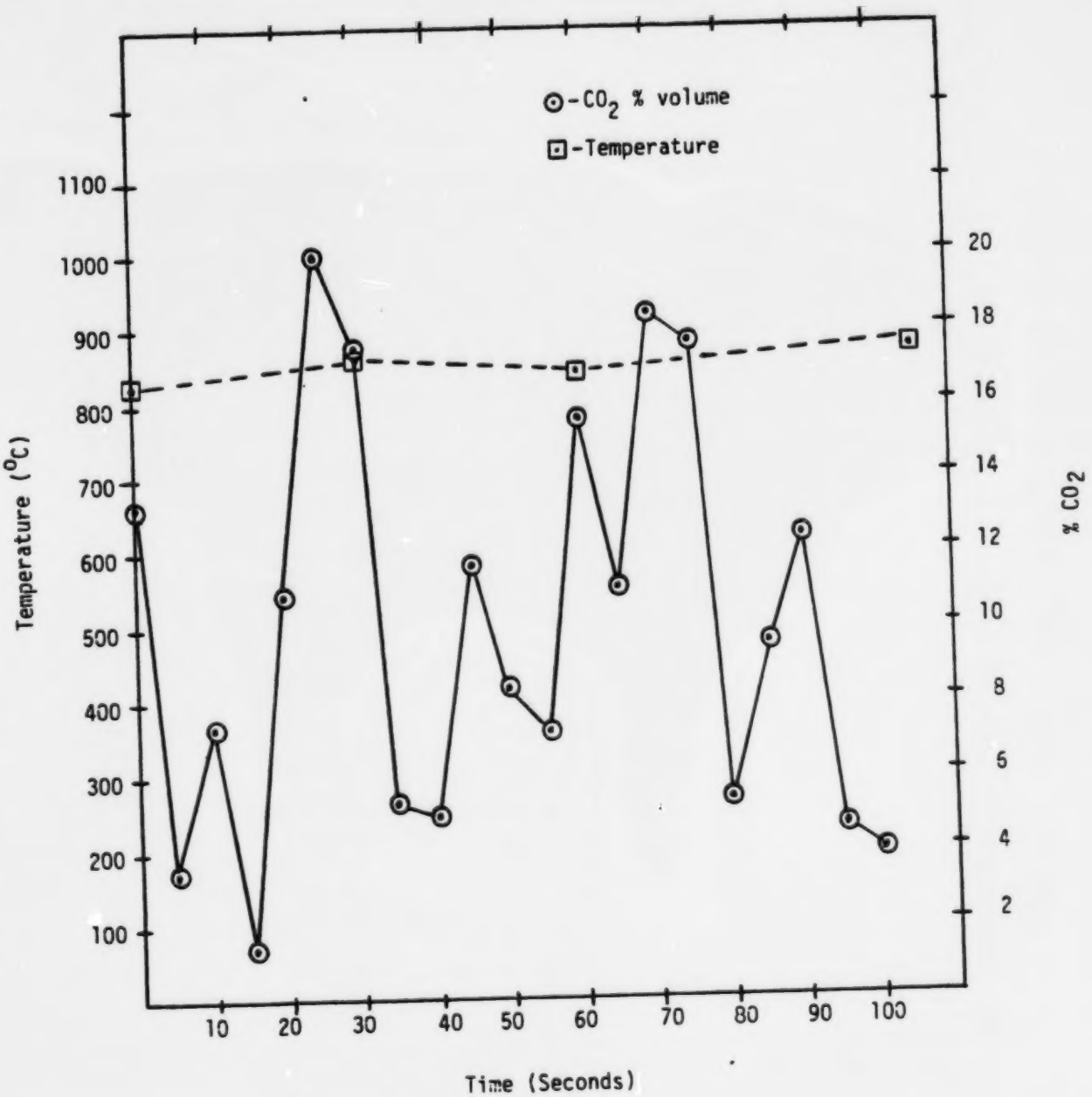


FIGURE 4: Fluctuations of Furnace Carbon Dioxide Readings Prior to the Sample Conditioning Package.

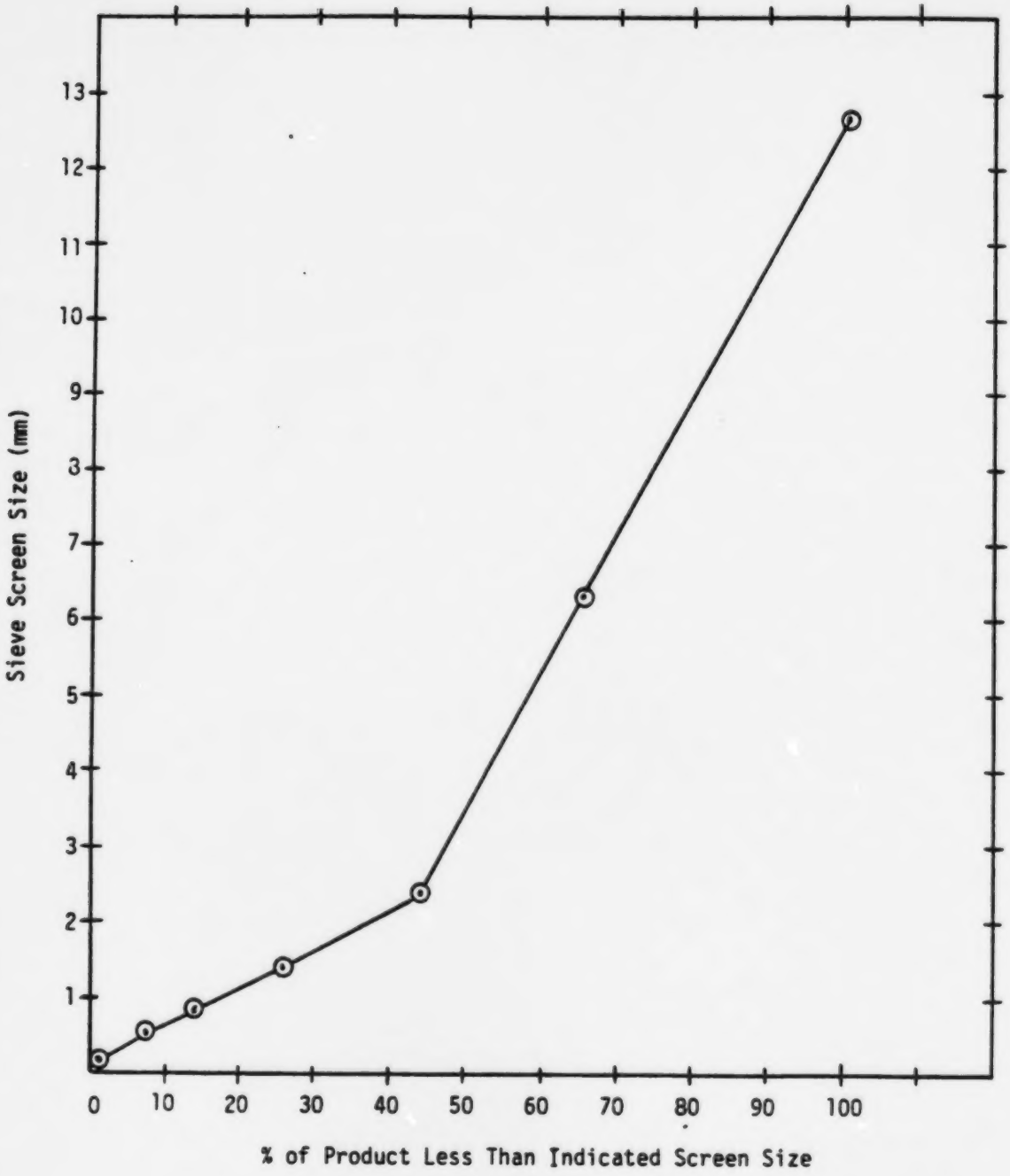


FIGURE 5: Typical Hog Fuel for Boiler Probe Tests

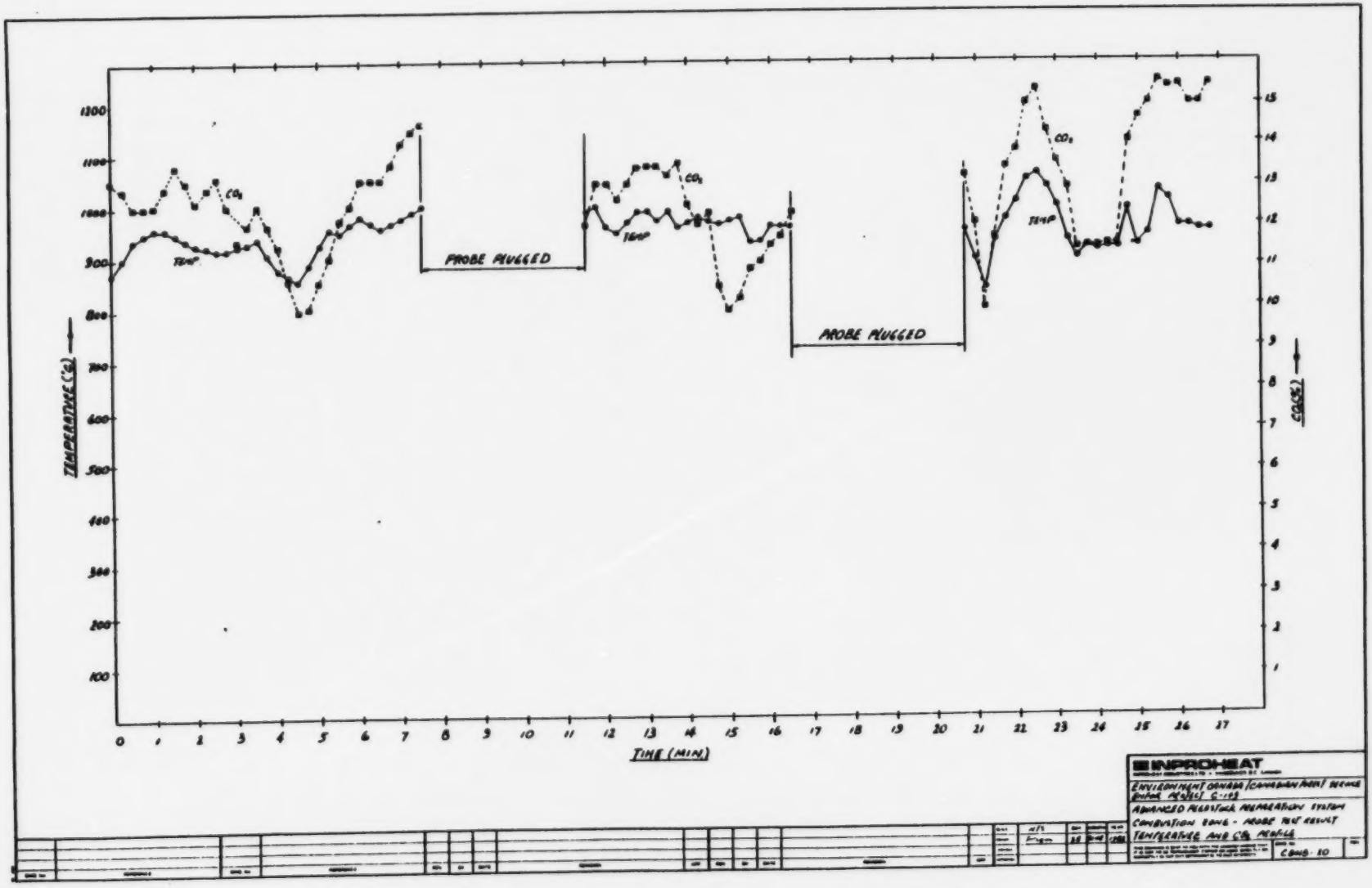


FIGURE 6: Carbon Dioxide Profile for Combustion Zone Test

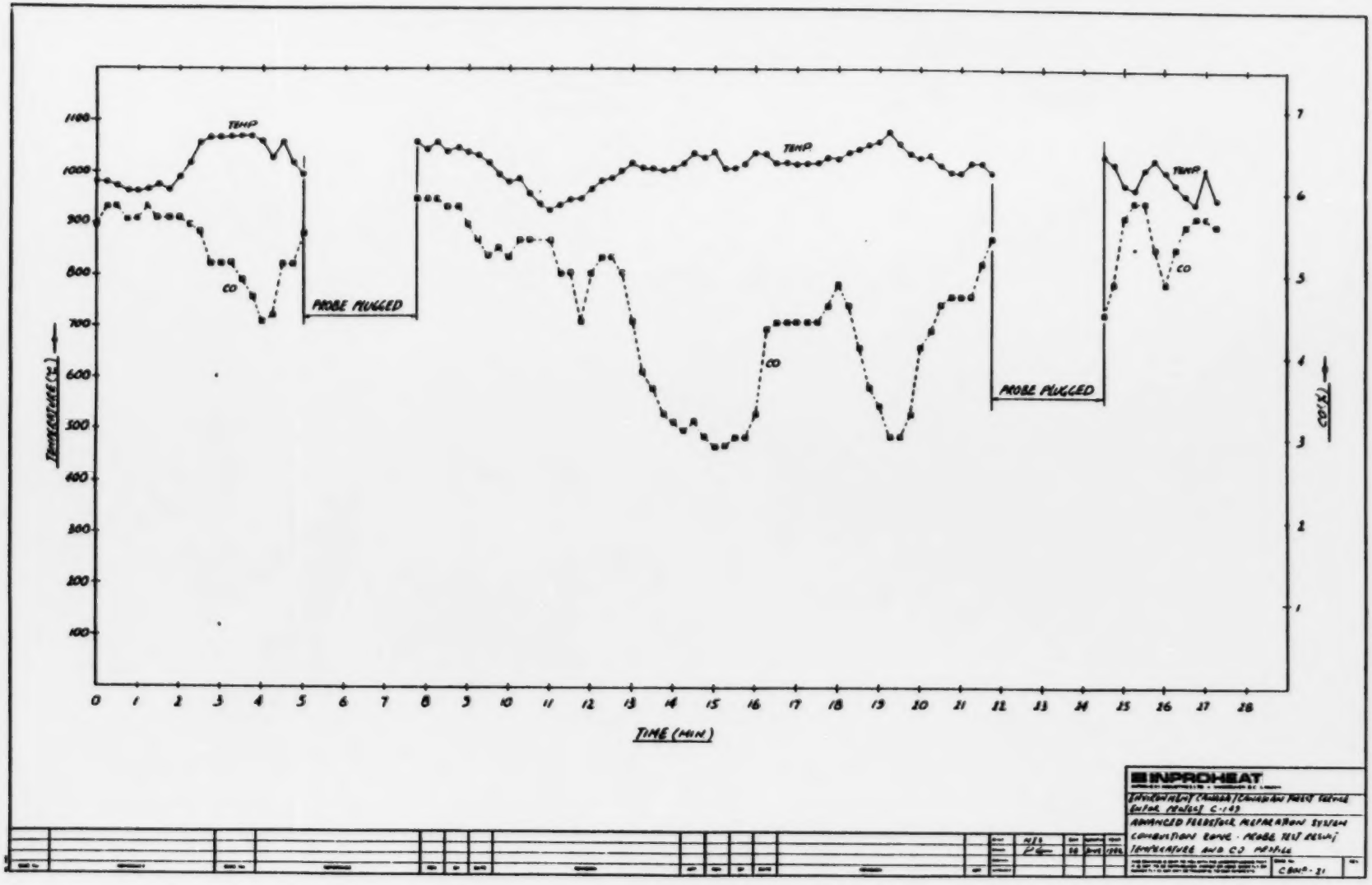


FIGURE 7: Carbon Monoxide Profile for Combustion Zone Test

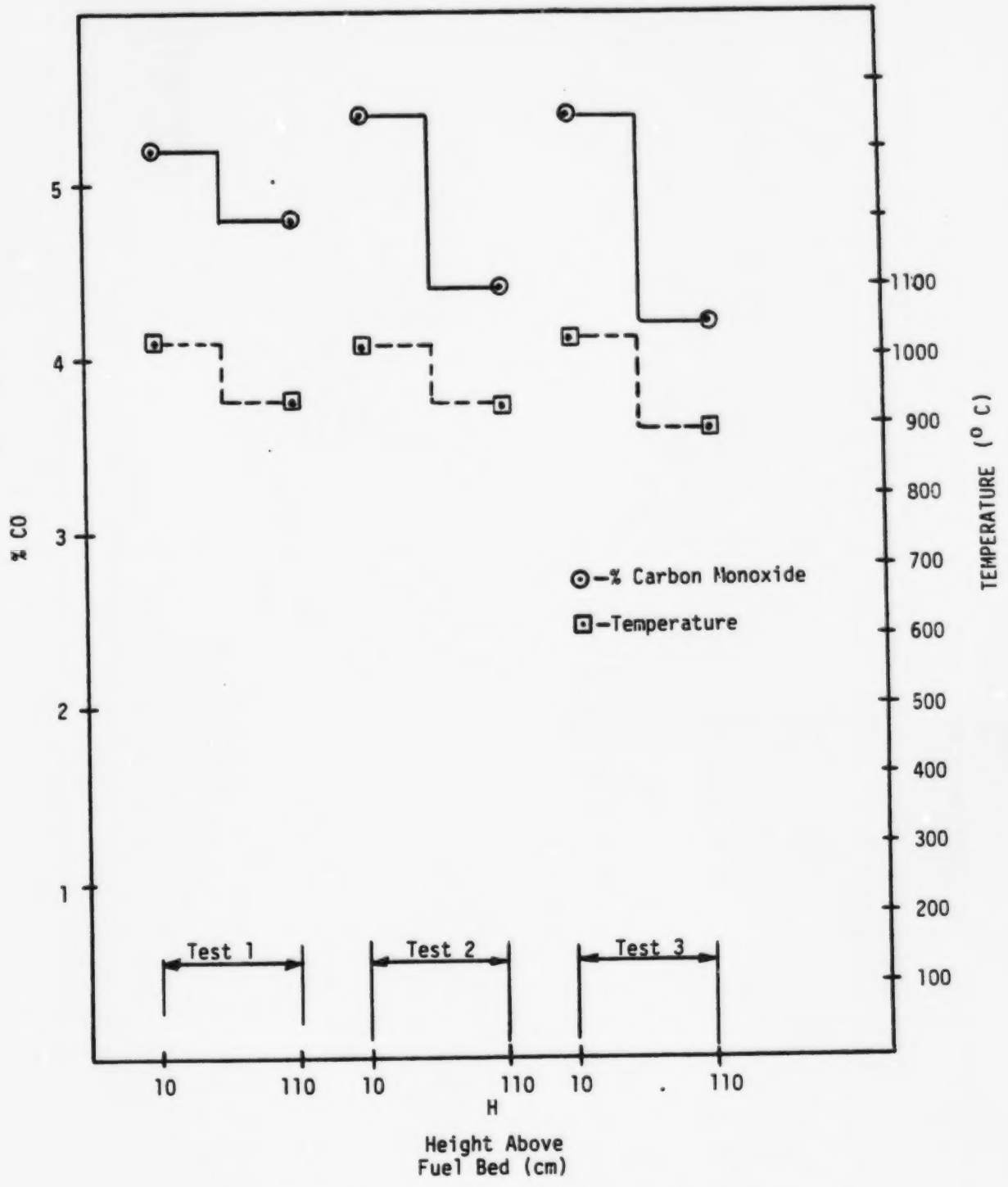


FIGURE 8: Variation of Carbon Monoxide and Temperature with Height above the Fuel Bed.

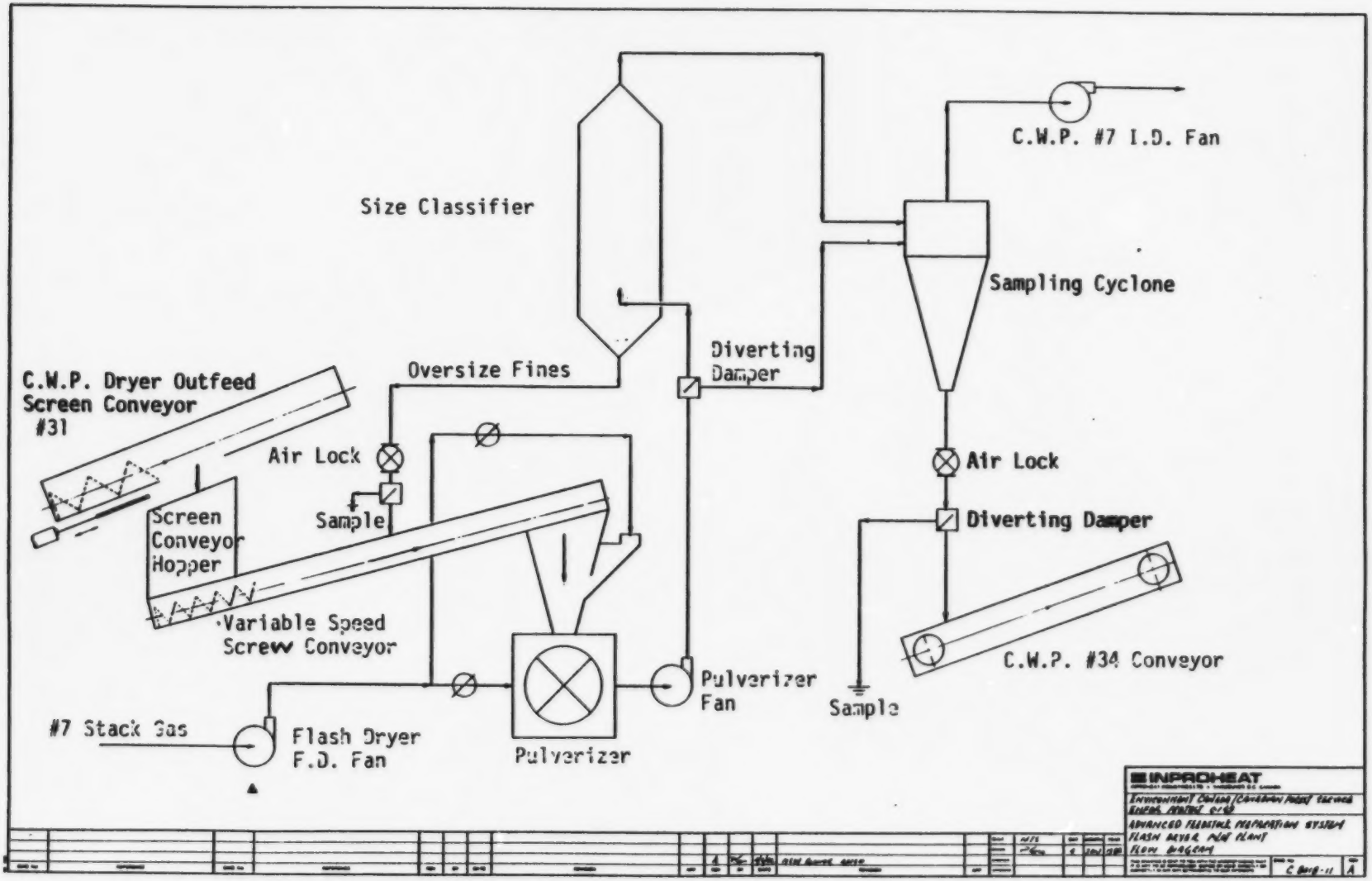


FIGURE 9: Pilot Plant Flow Schematic

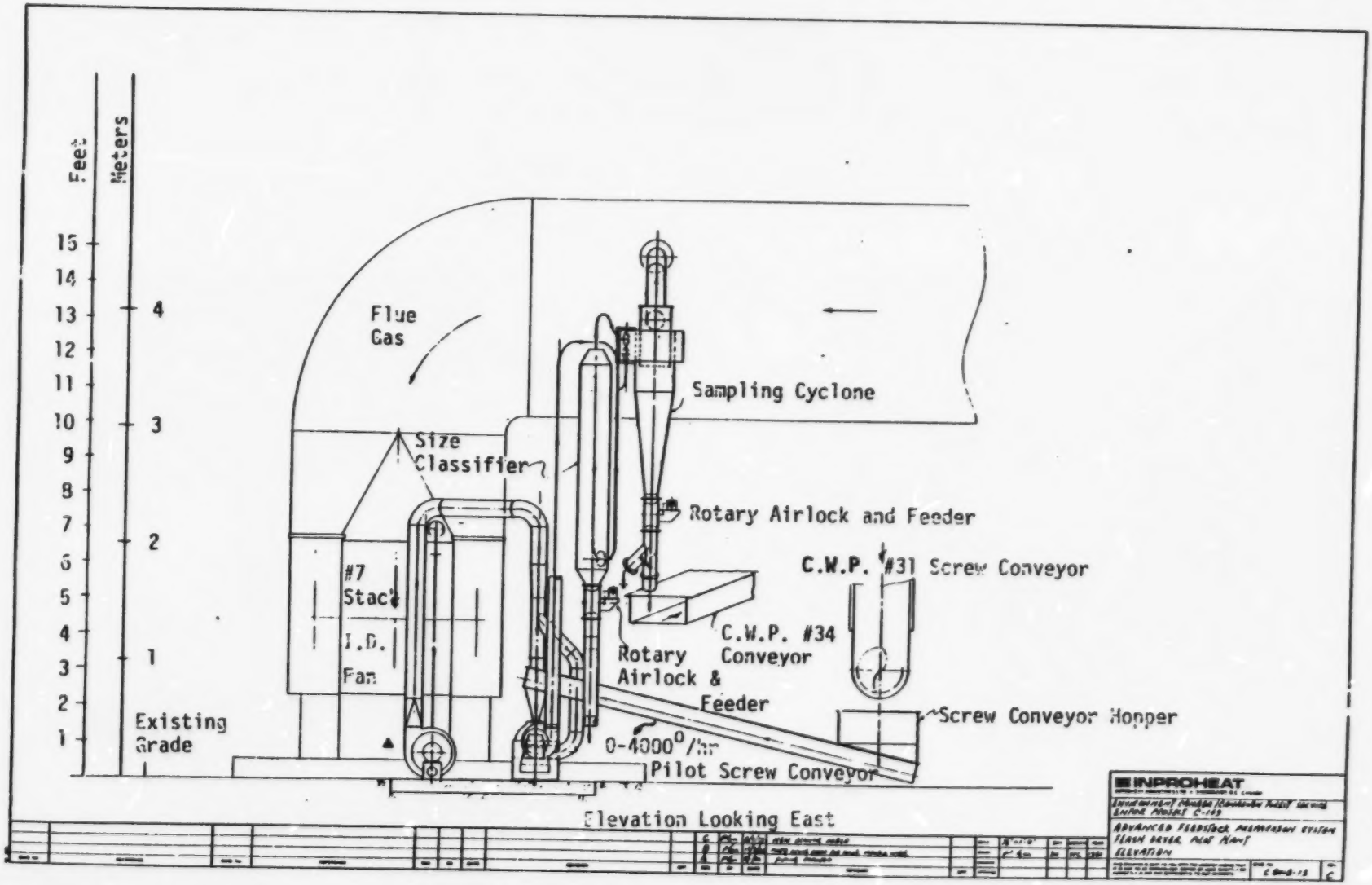


FIGURE 10: Pilot Plant Elevation

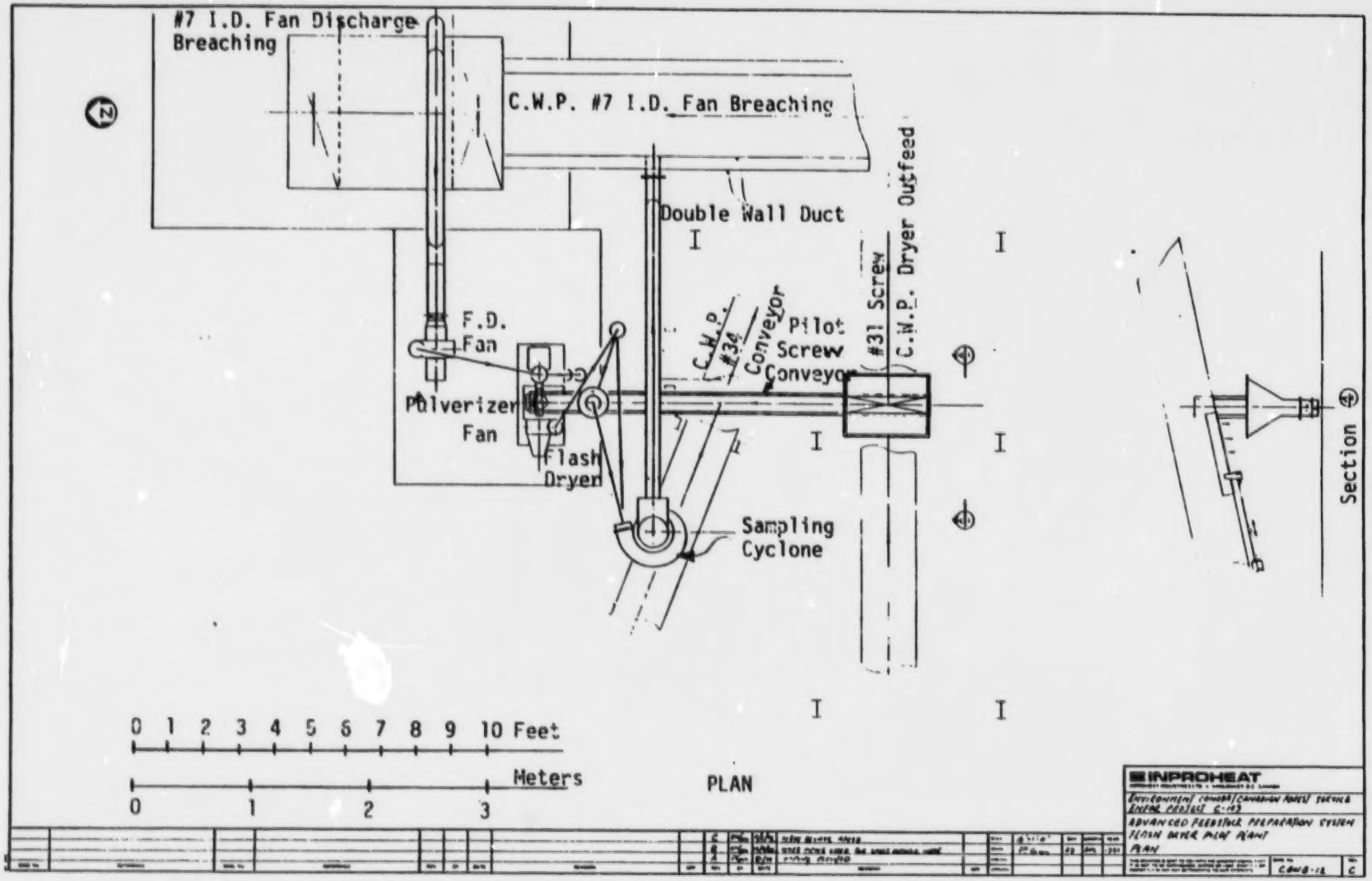
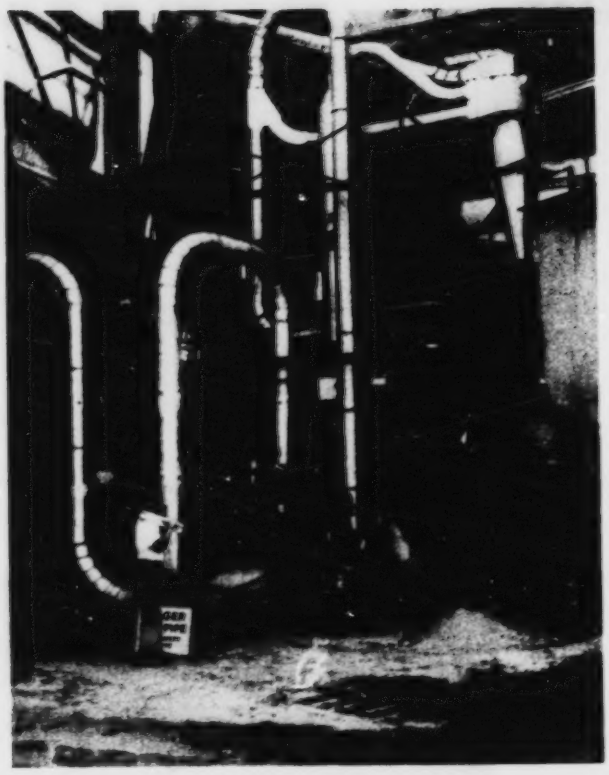


FIGURE 11: Pilot Plant Plan

INPROHEAT



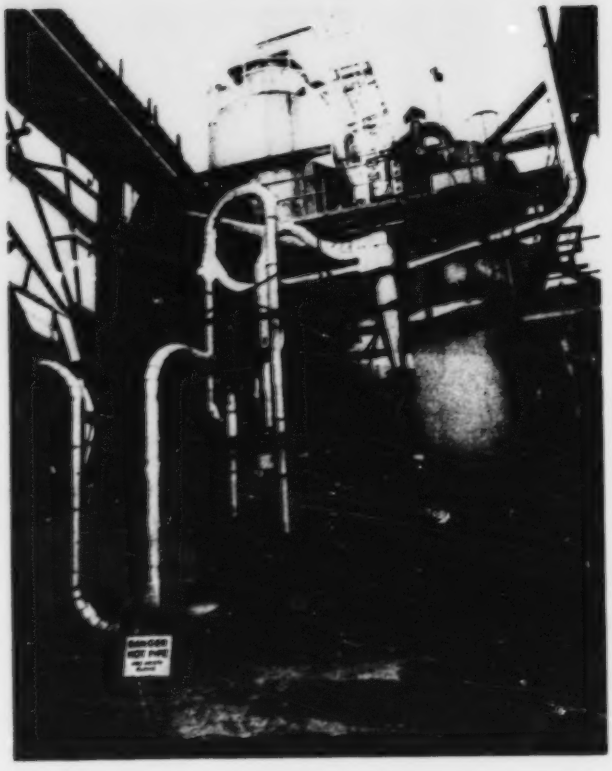
Cyclone

Cyclone Discharge to C.W.P. Conveyor #34

Flash Dryer Discharge Sample Point

Pulverizer

F.D. Fan



Cyclone Gas Discharge to C.W.P. #7 I.D. Fan Breaching

Stack Gas Inlet

FIGURE 12: Flash Dryer Pilot Plant Located at Canadian White Pine

Abort
Gate

FIGURE 13: Flash Dryer Screw Conveyor and Inlet Hopper

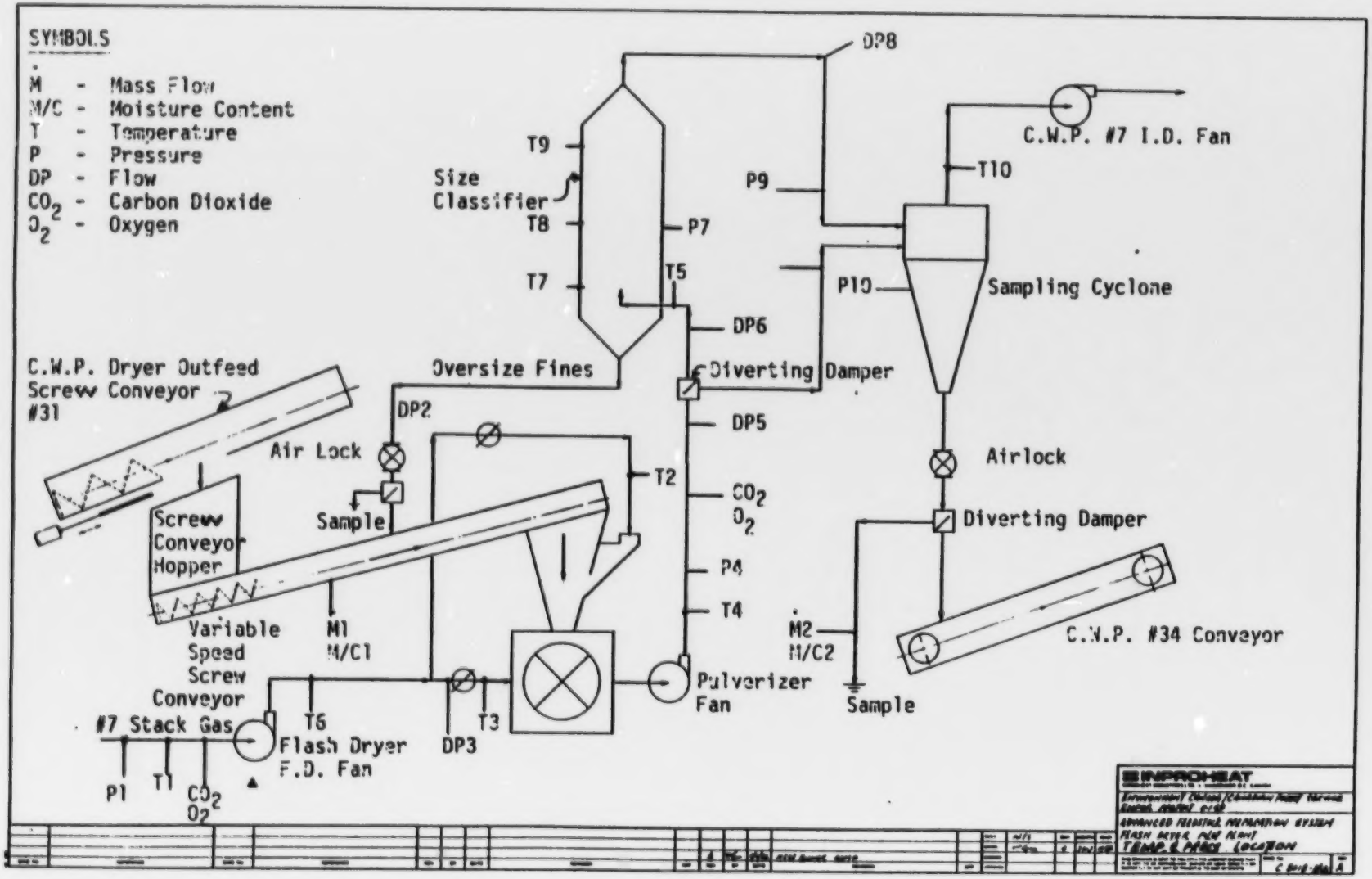


FIGURE 14: Pilot Plant Monitoring

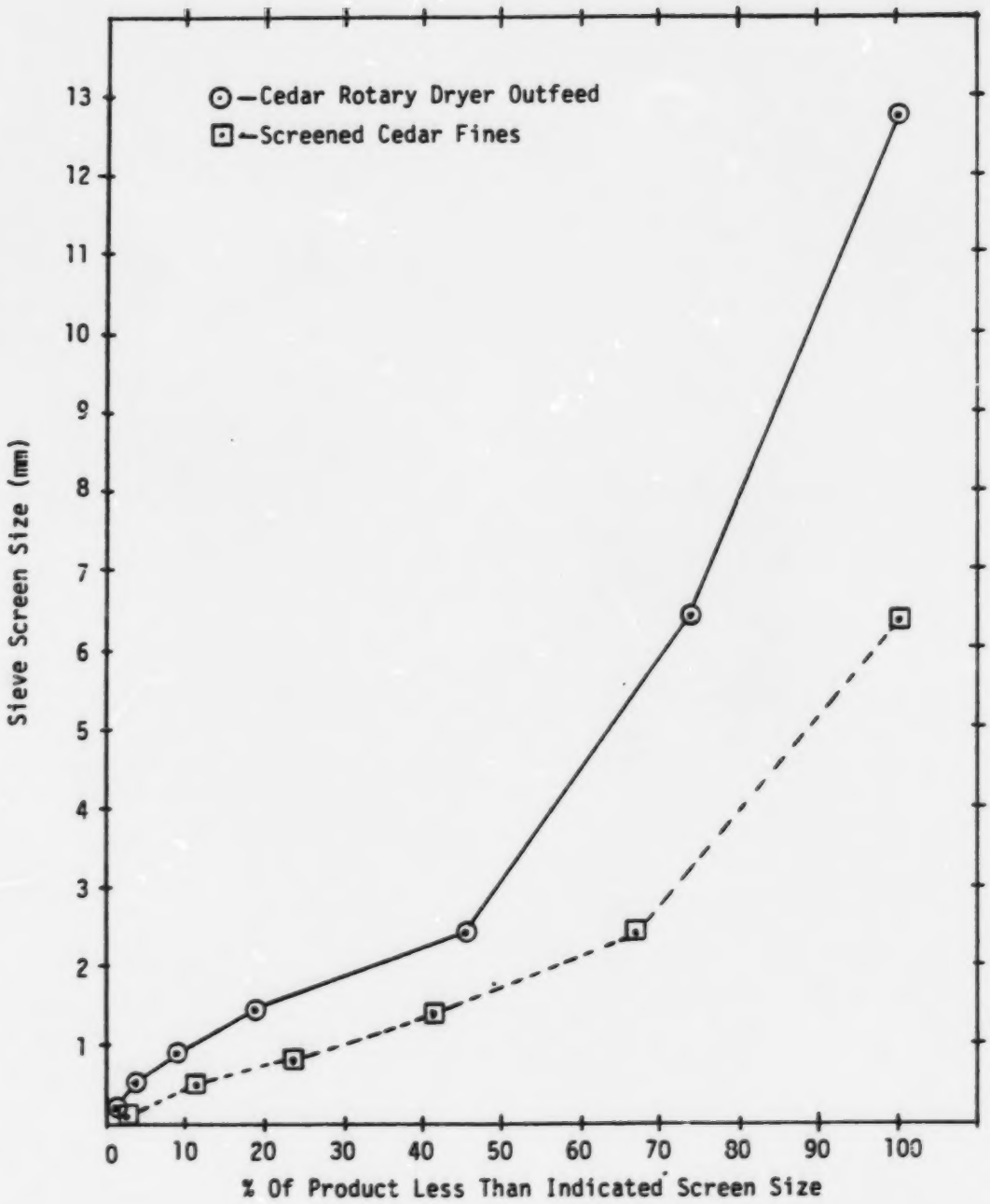


FIGURE 15: Size Distribution for Typical Flash Dryer Infeeds

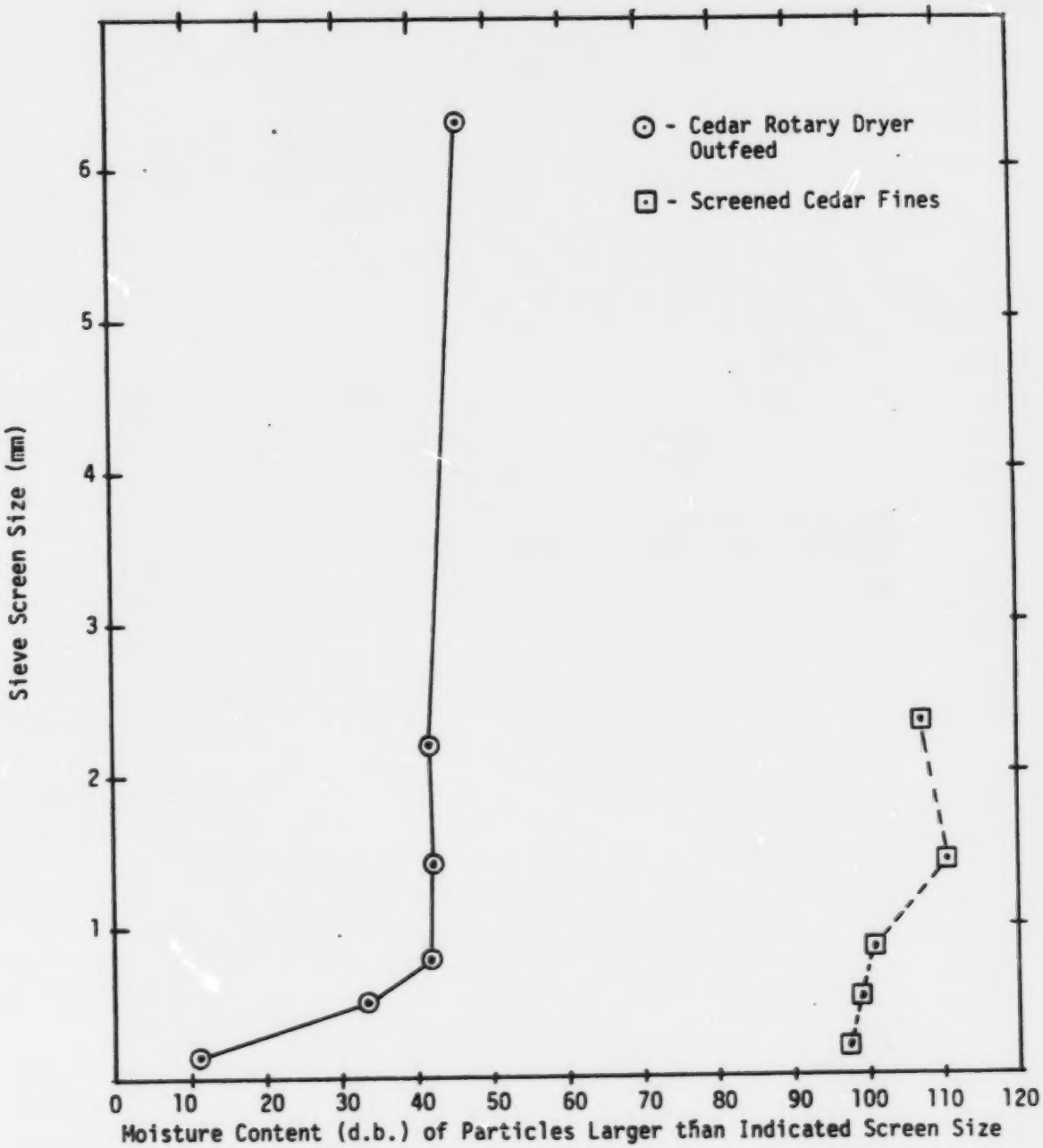


FIGURE 16: Variation in Particle Moisture Content for Flash Dryer Infeeds

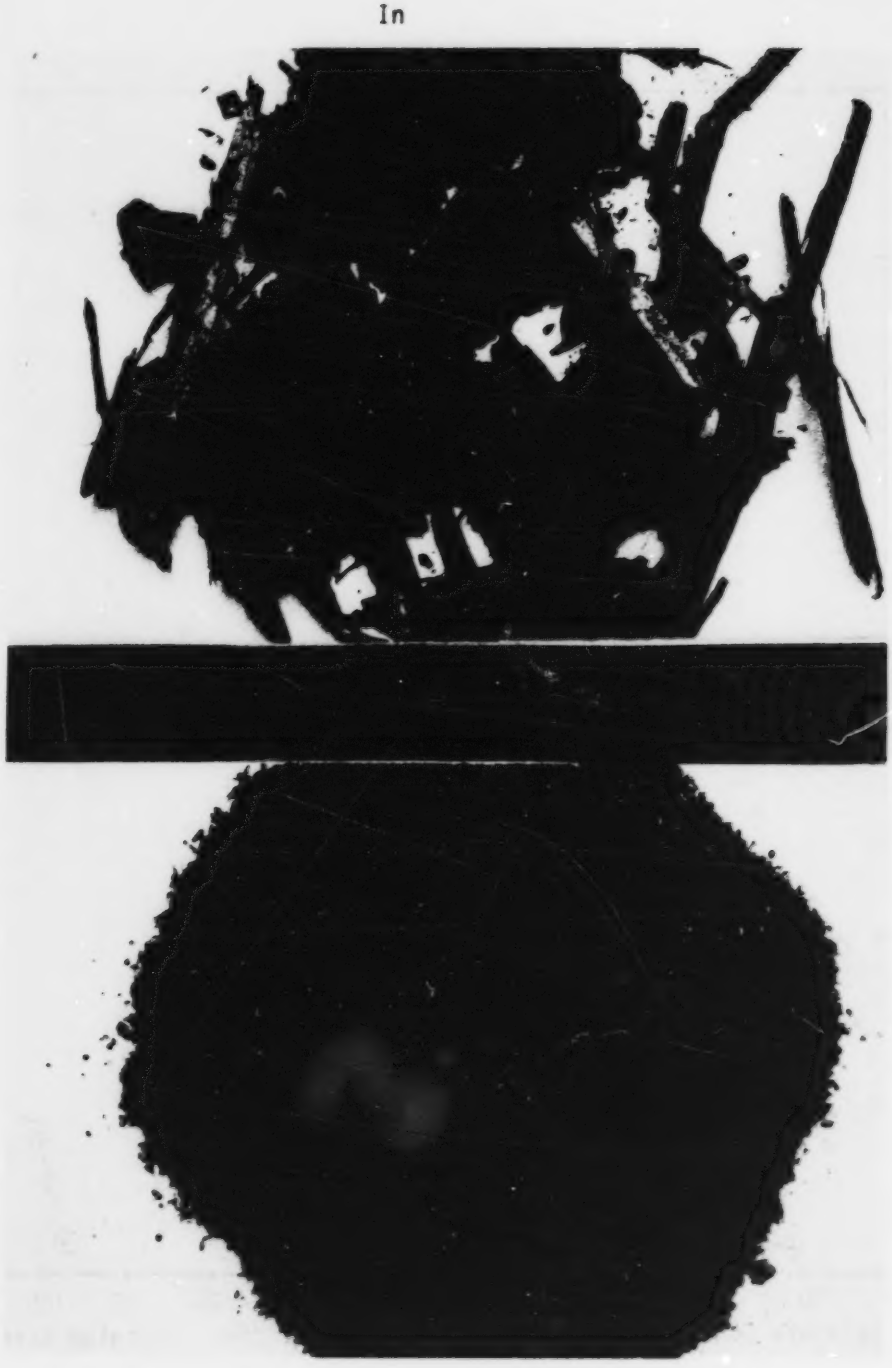


FIGURE 17: Flash Dried Cedar Rotary Dryer Outfeed

In

Inches

Centimeters

Out

FIGURE 18: Flash Dried Screened Cedar Fines

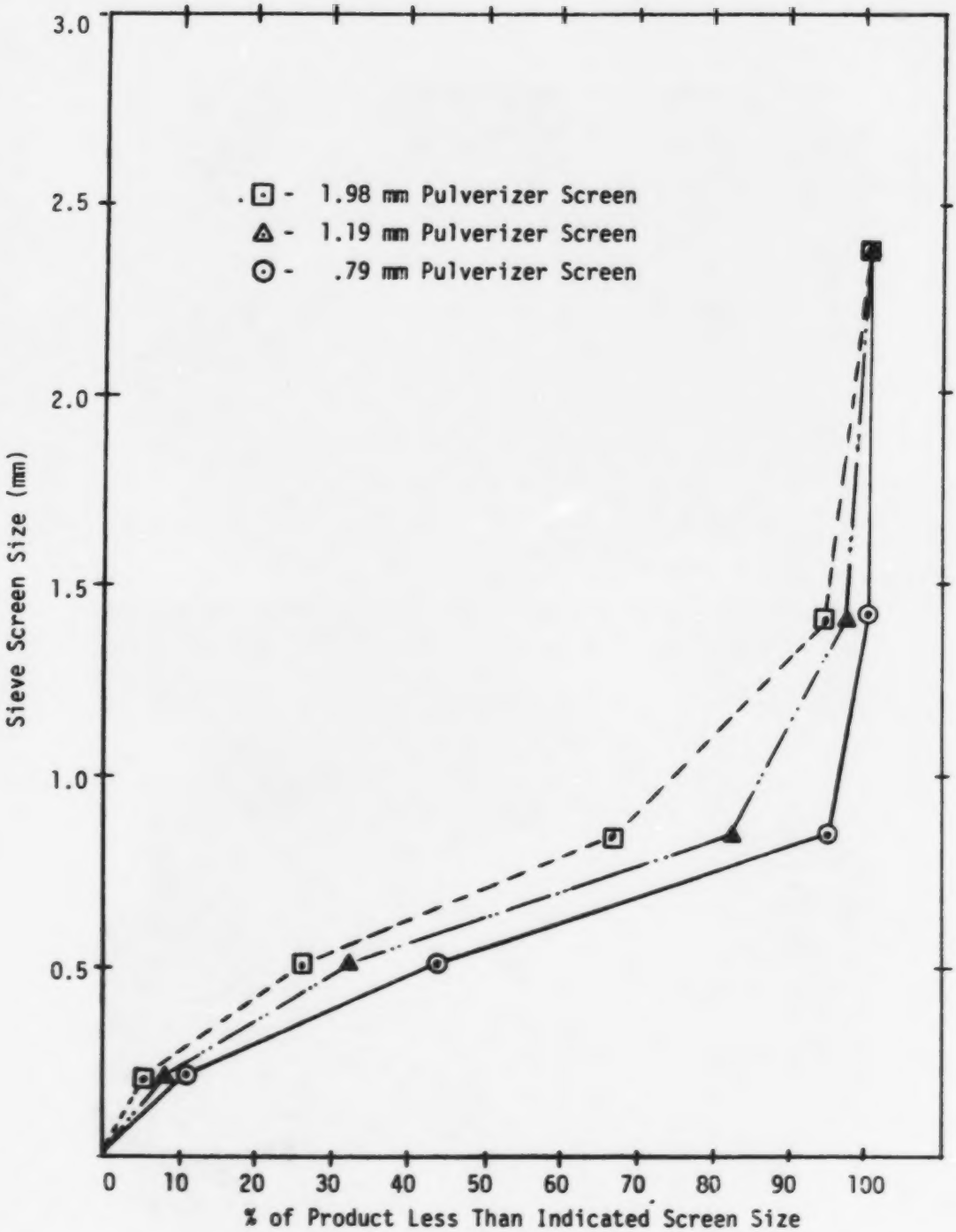


FIGURE 19: Variation of Output Product Size Distribution with Pulverizer Screen Size

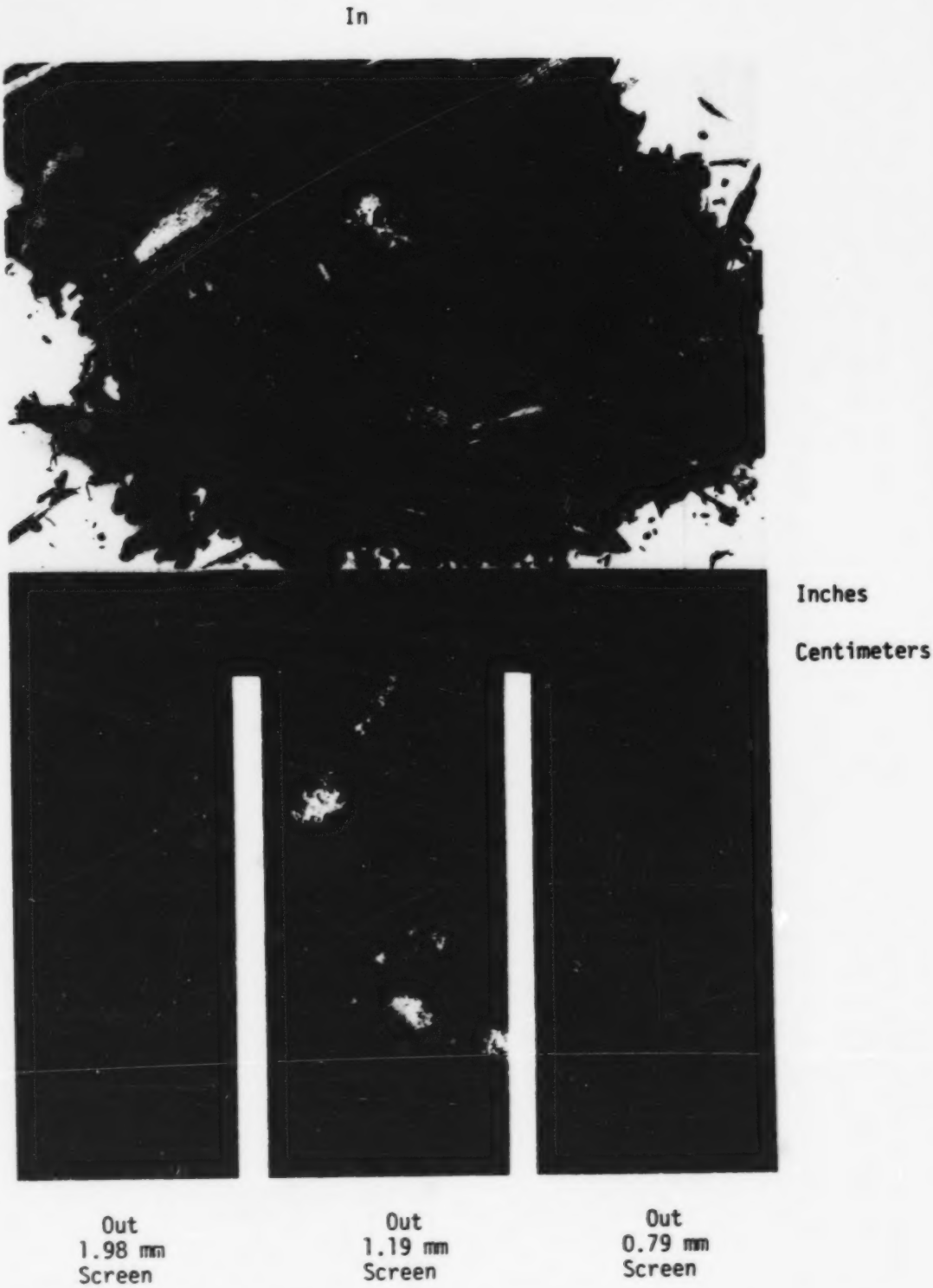


FIGURE 20: Comparison of Flash Dryer Discharges for Different Pulverizer Discharge Screens

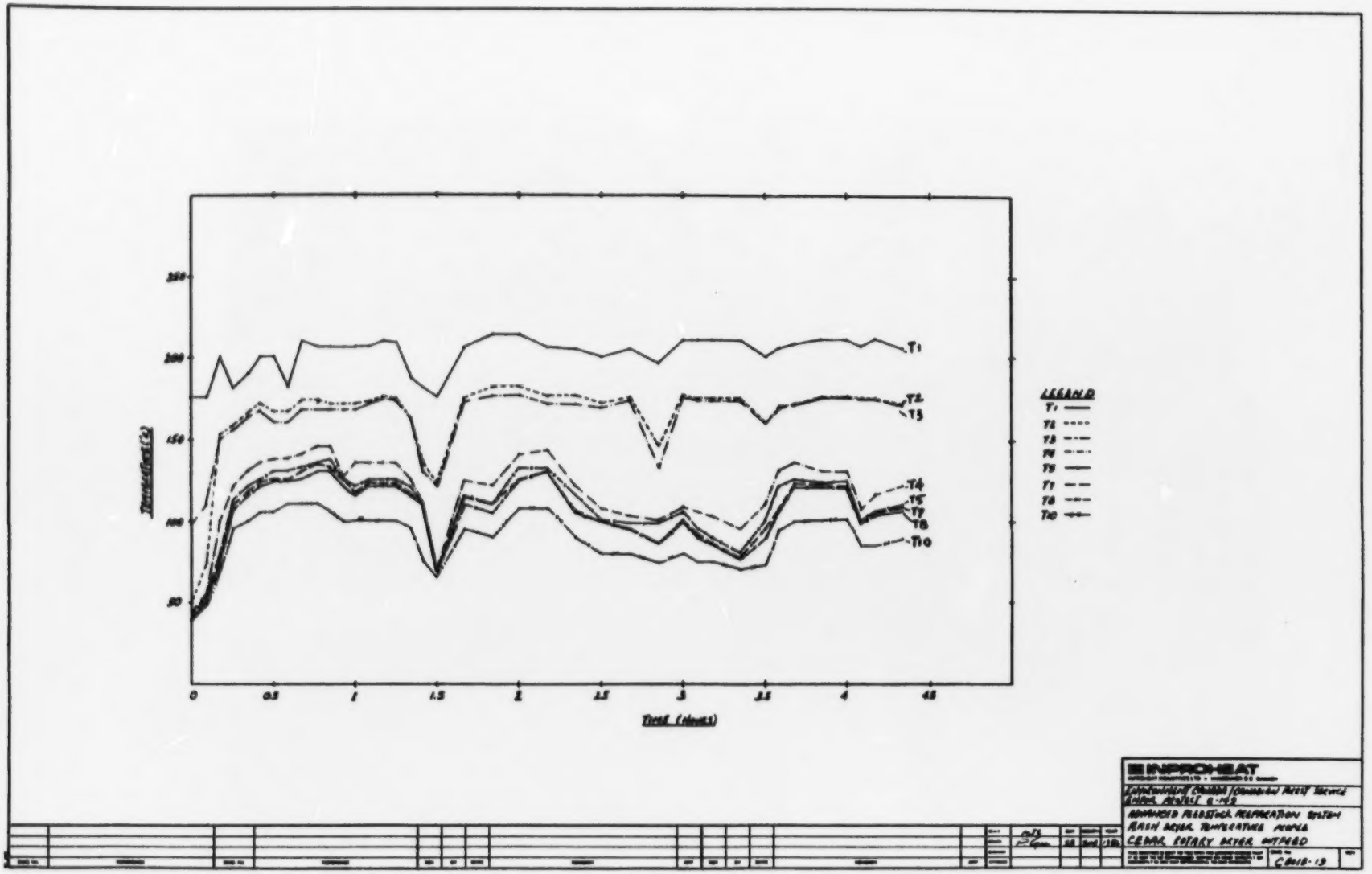


FIGURE 21: Test A - Full Temperature Profile for Cedar Rotary Dryer Outfeed

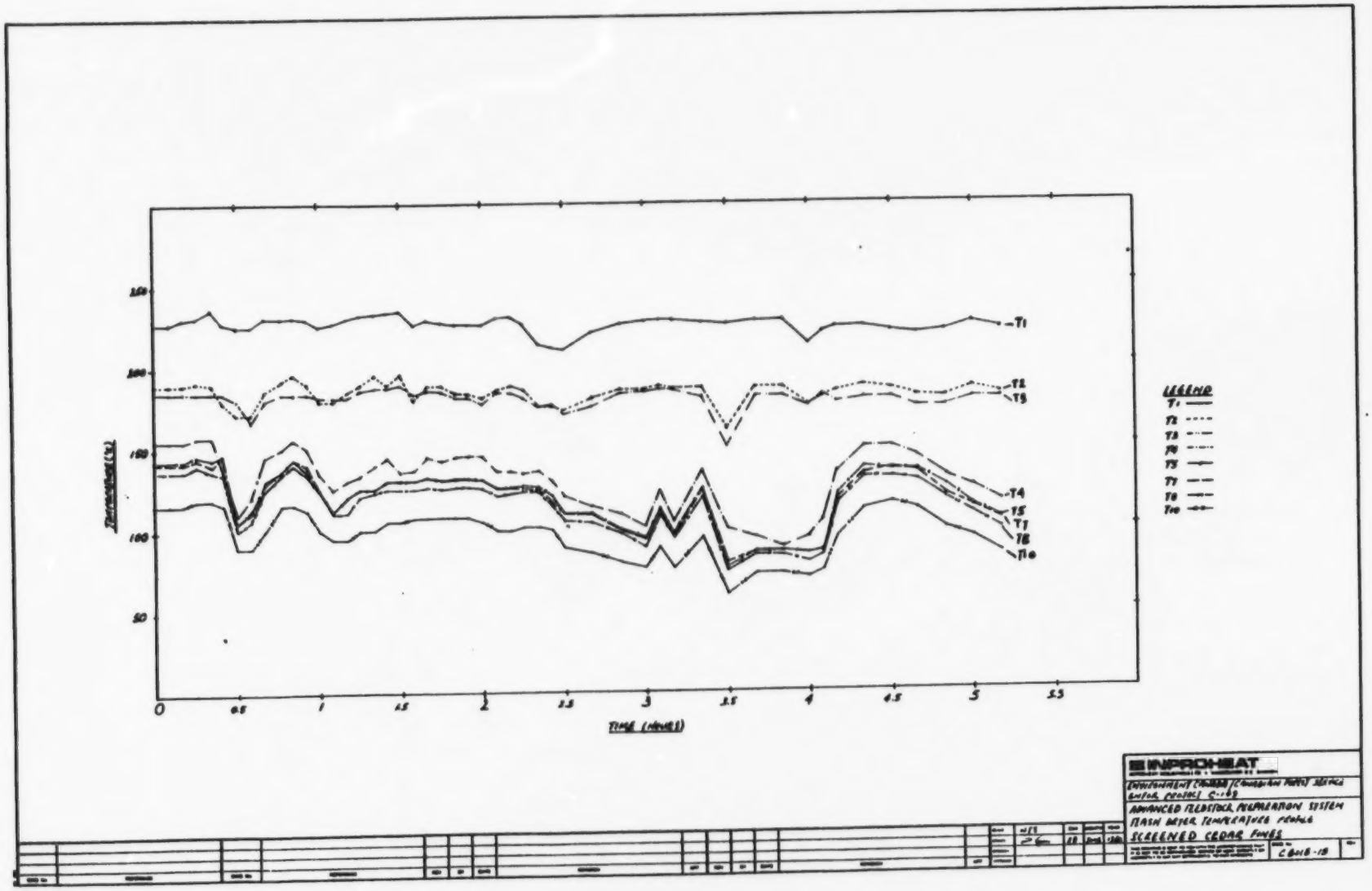


FIGURE 22: Test B - Full Temperature Profile for Screened Cedar Fines

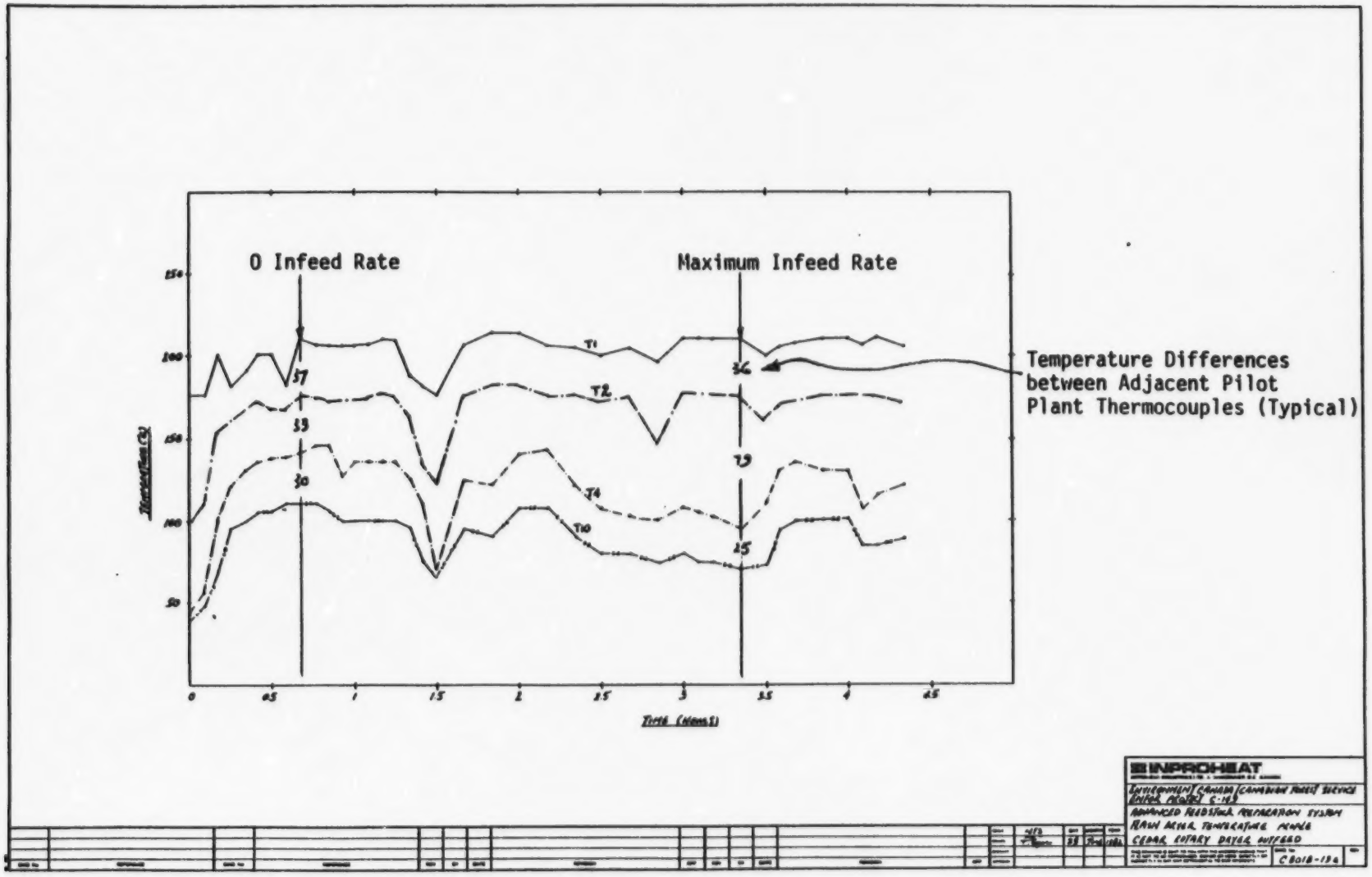


FIGURE 23: Test A - Partial Temperature Profile for Cedar Rotary Dryer Outfeed

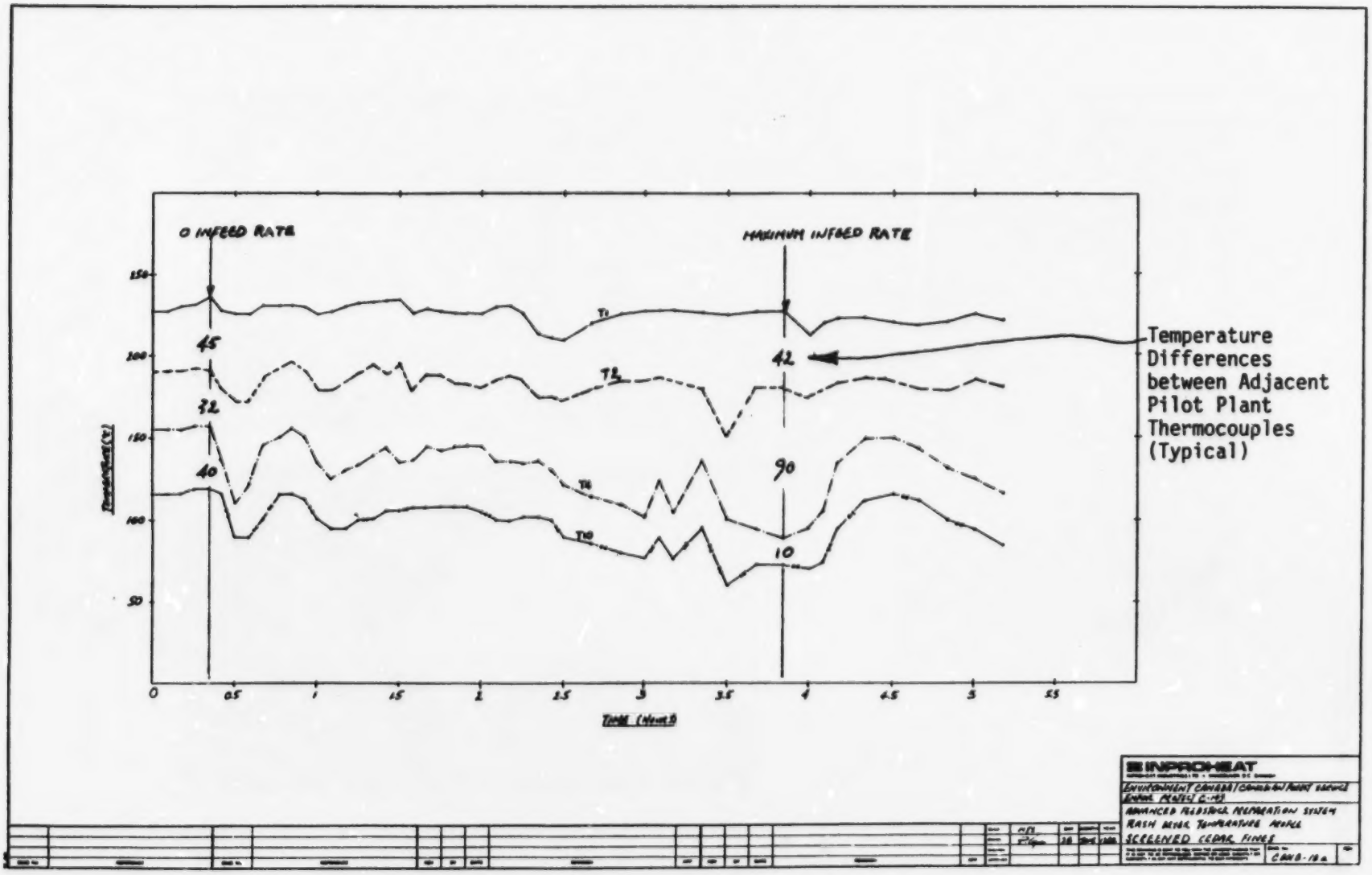


FIGURE 24: Test B - Partial Temperature Profile for Screened Cedar Fines

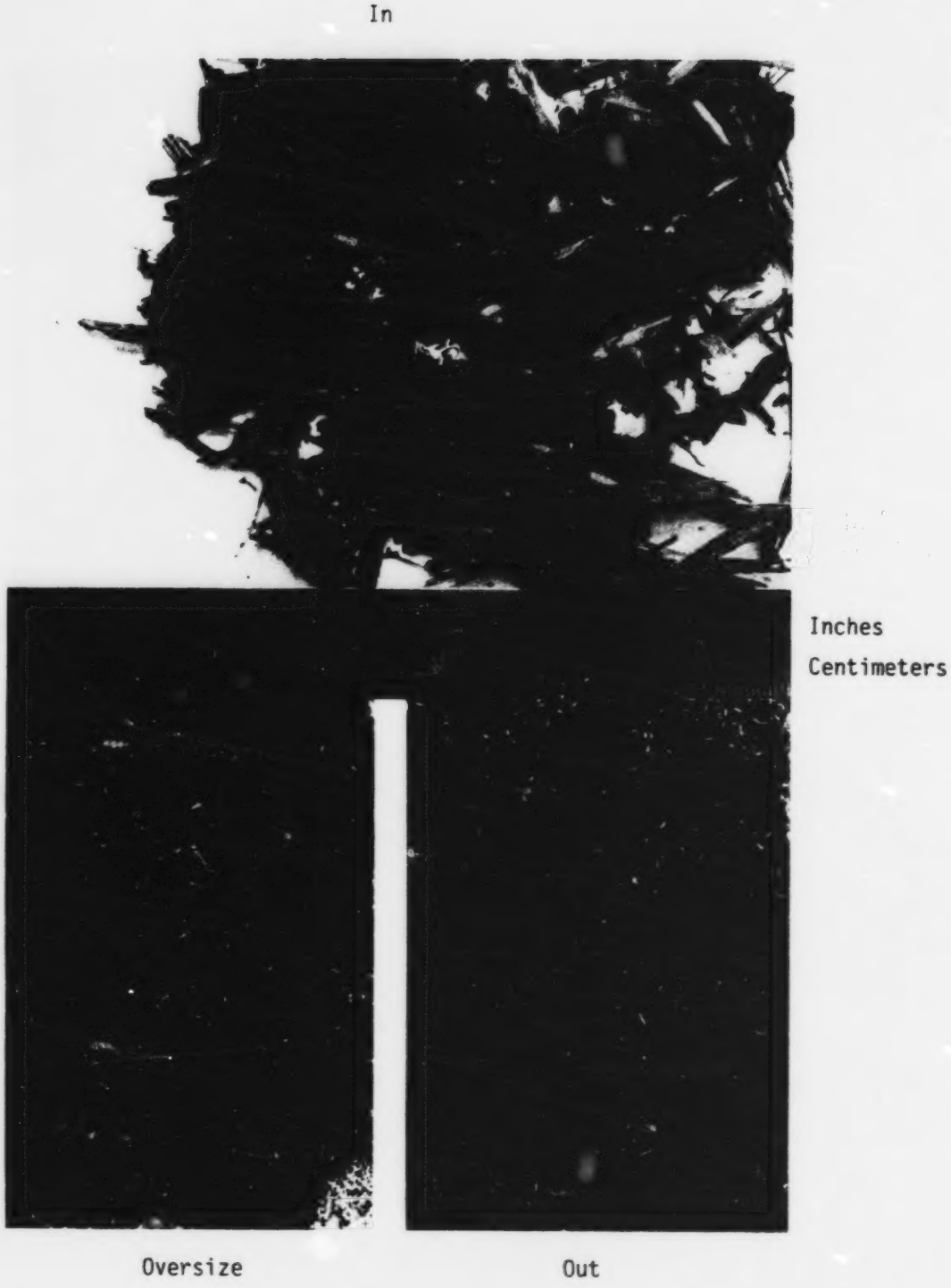


FIGURE 25: Comparison Between Oversize Discharge and Cyclone Discharge for Flash Dried Cedar Rotary Dryer Outfeed

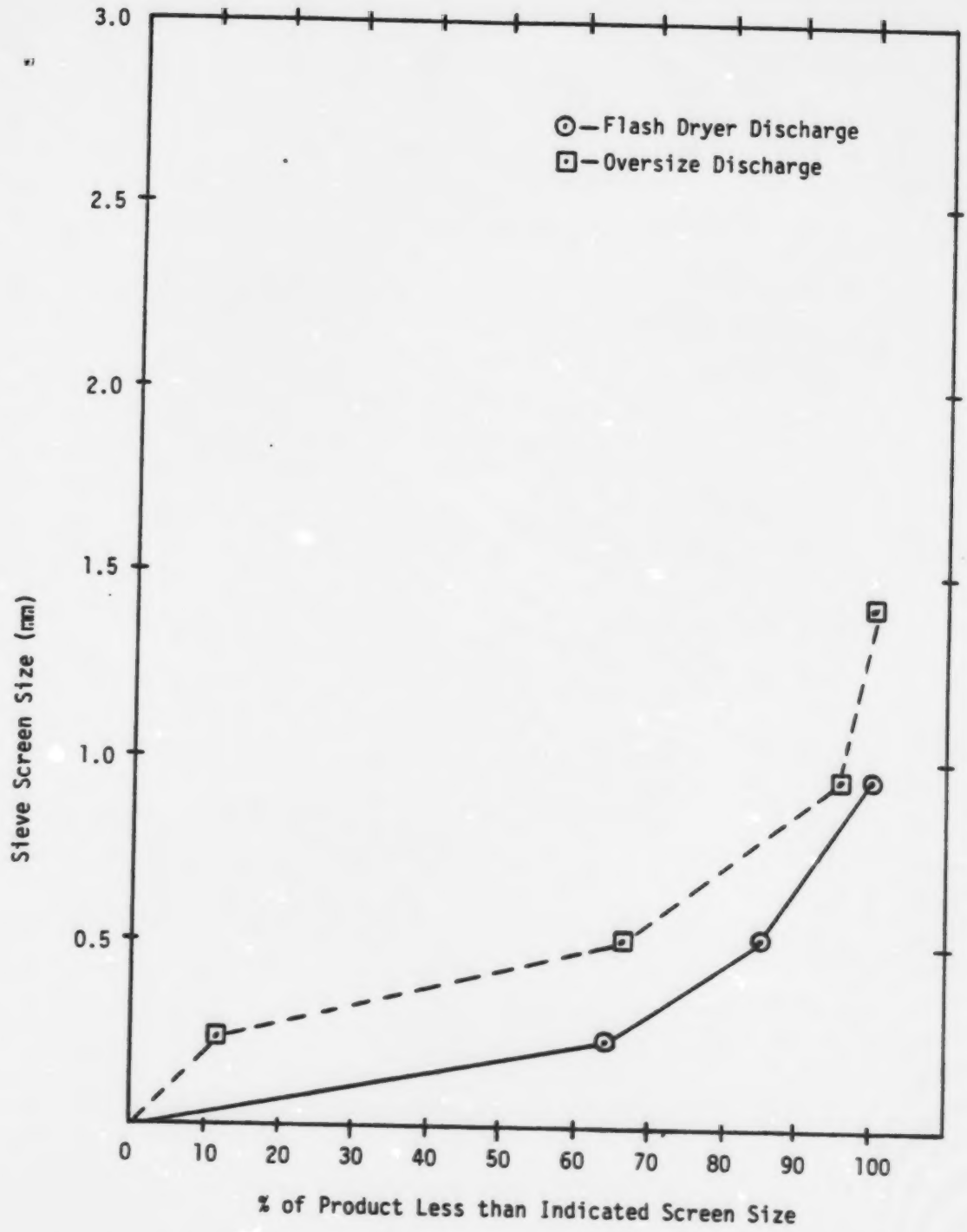


FIGURE 26: Typical Size Variation Between Oversize Discharge and Flash Dryer Discharge

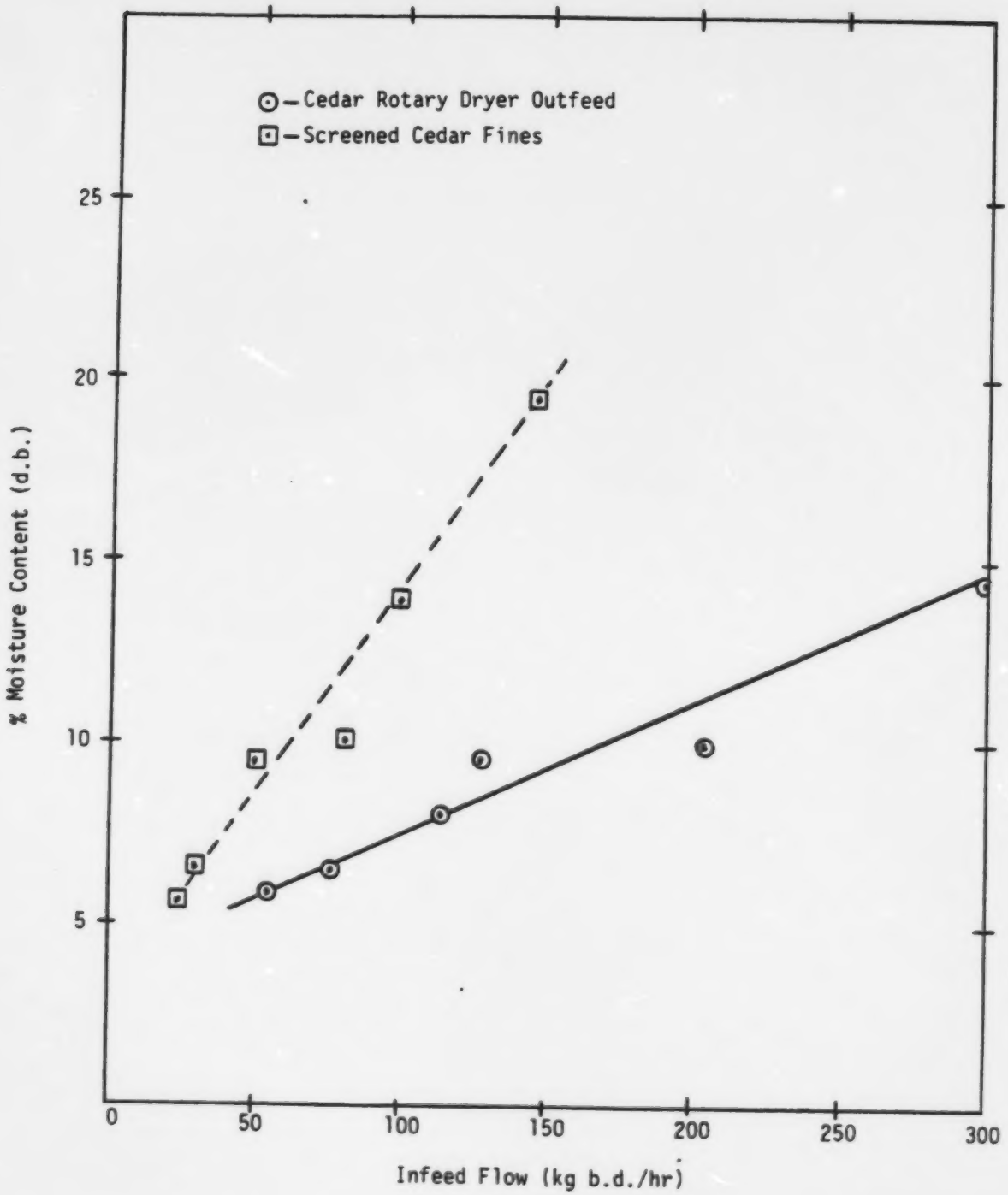


FIGURE 27: Variation of Flash Dryer Discharge Product Moisture Content with Infeed Flow.

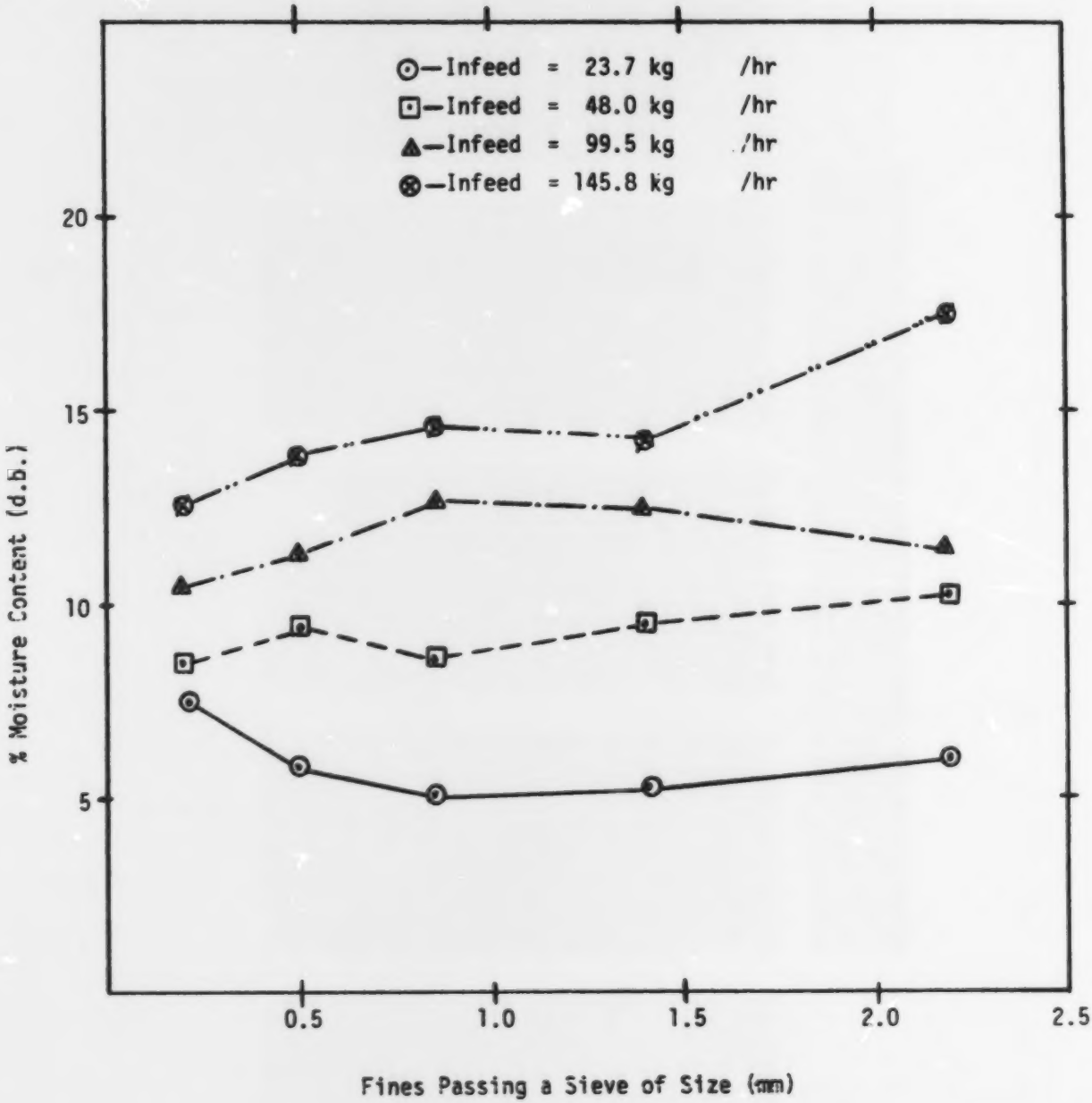


FIGURE 28: Variation of the Moisture Content of Flash Dried Screened Cedar Fines with Particle Size and Infeed Flow.

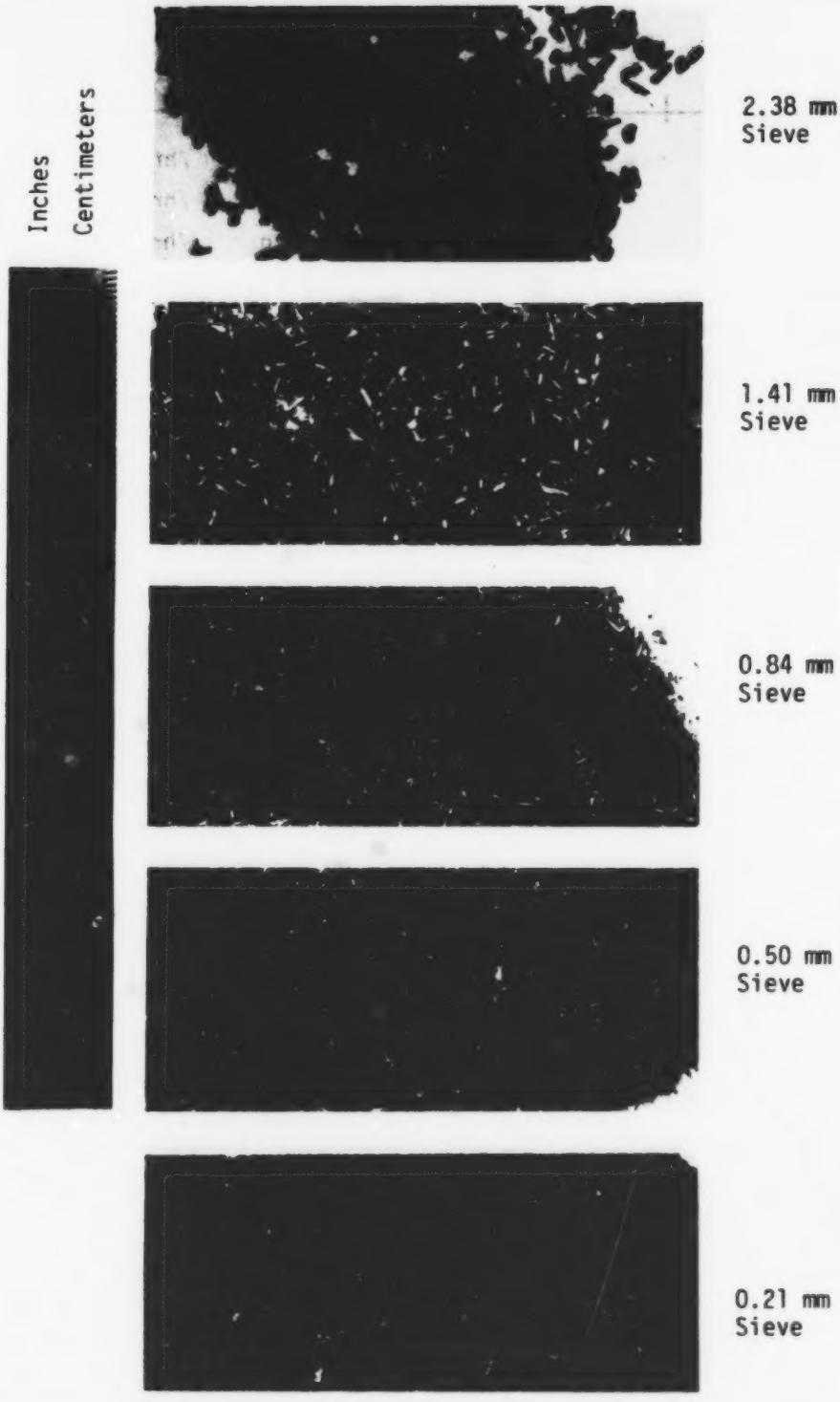


FIGURE 29: Comparison of Flash Dried Product Passing Through Sieves of Different Sizes

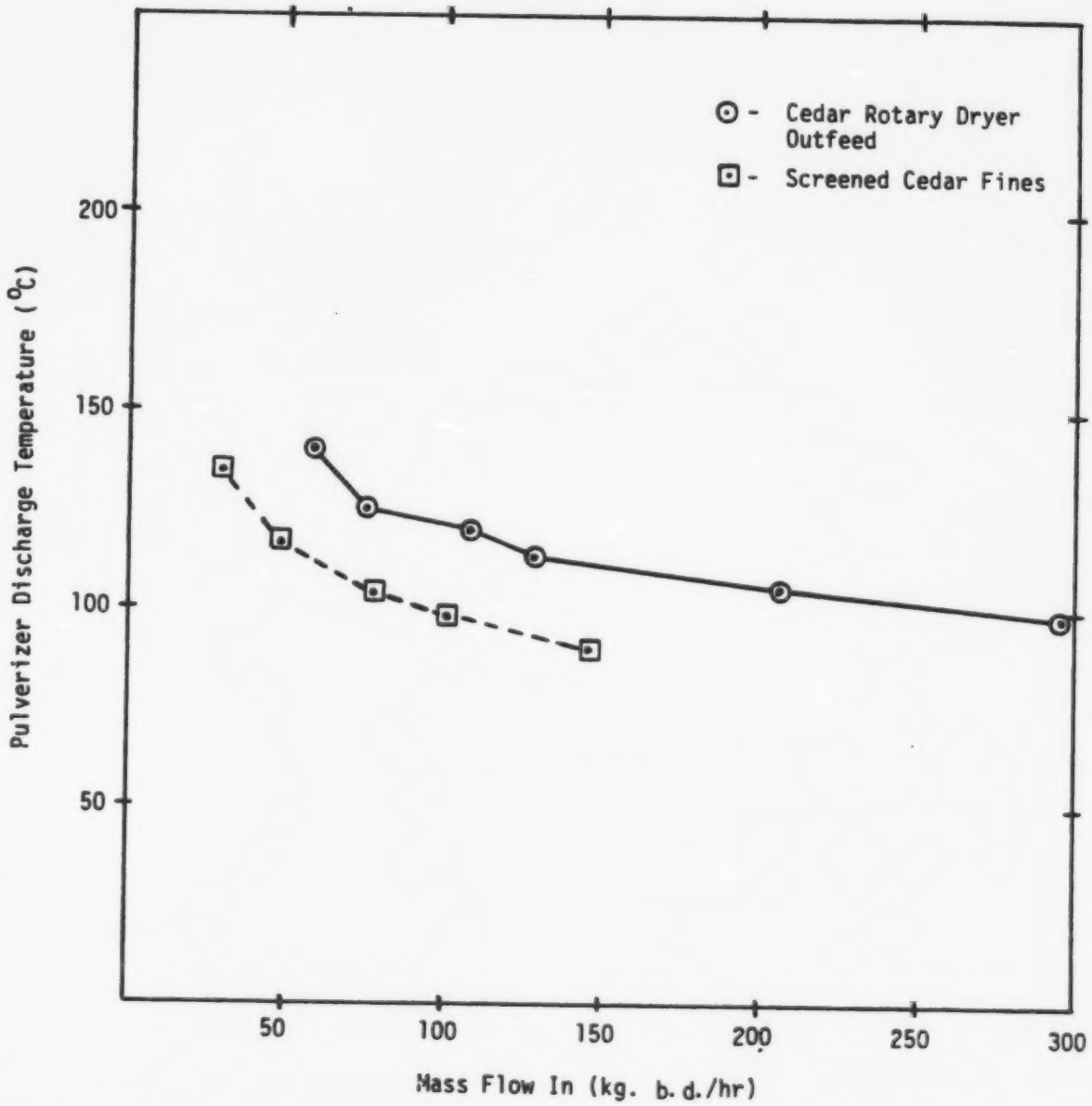


FIGURE 30: Variation in Pulverizer Discharge Temperature with Flash Dryer Infeed Rate.

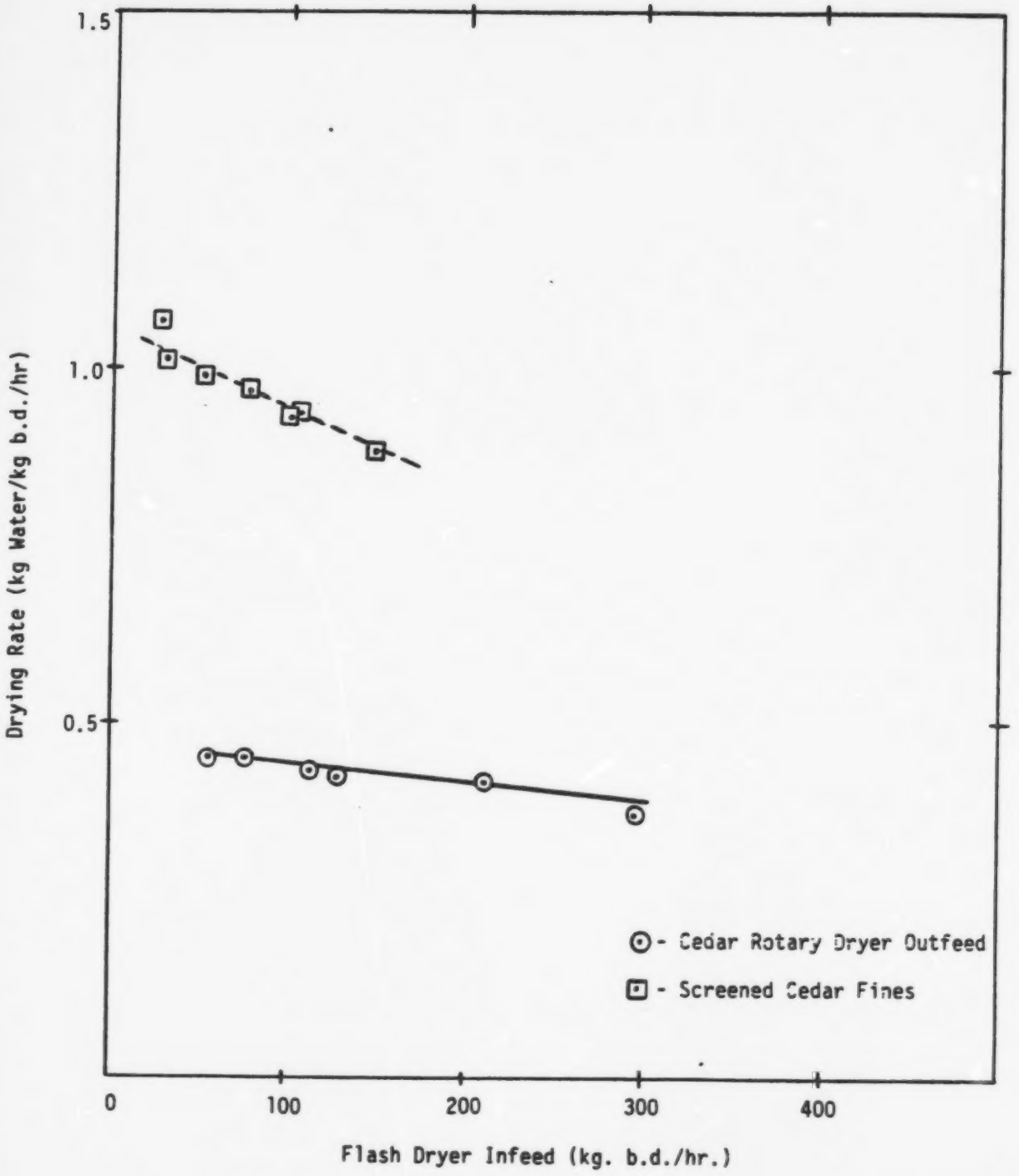


FIGURE 31: Variation of Drying Rate with Flash Dryer Infeed.

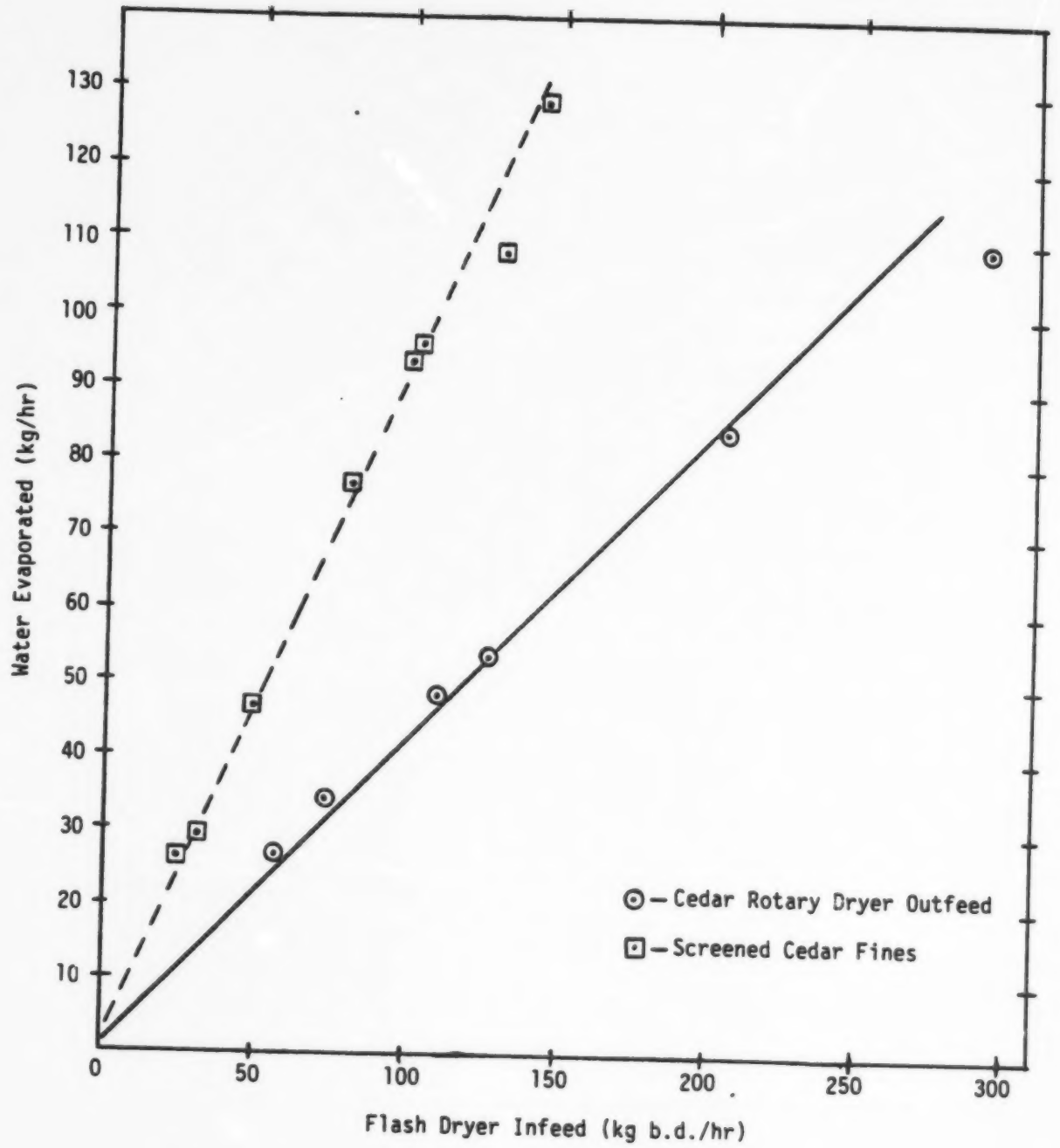


FIGURE 32: Variation of Water Evaporated with Rate of Infeed.

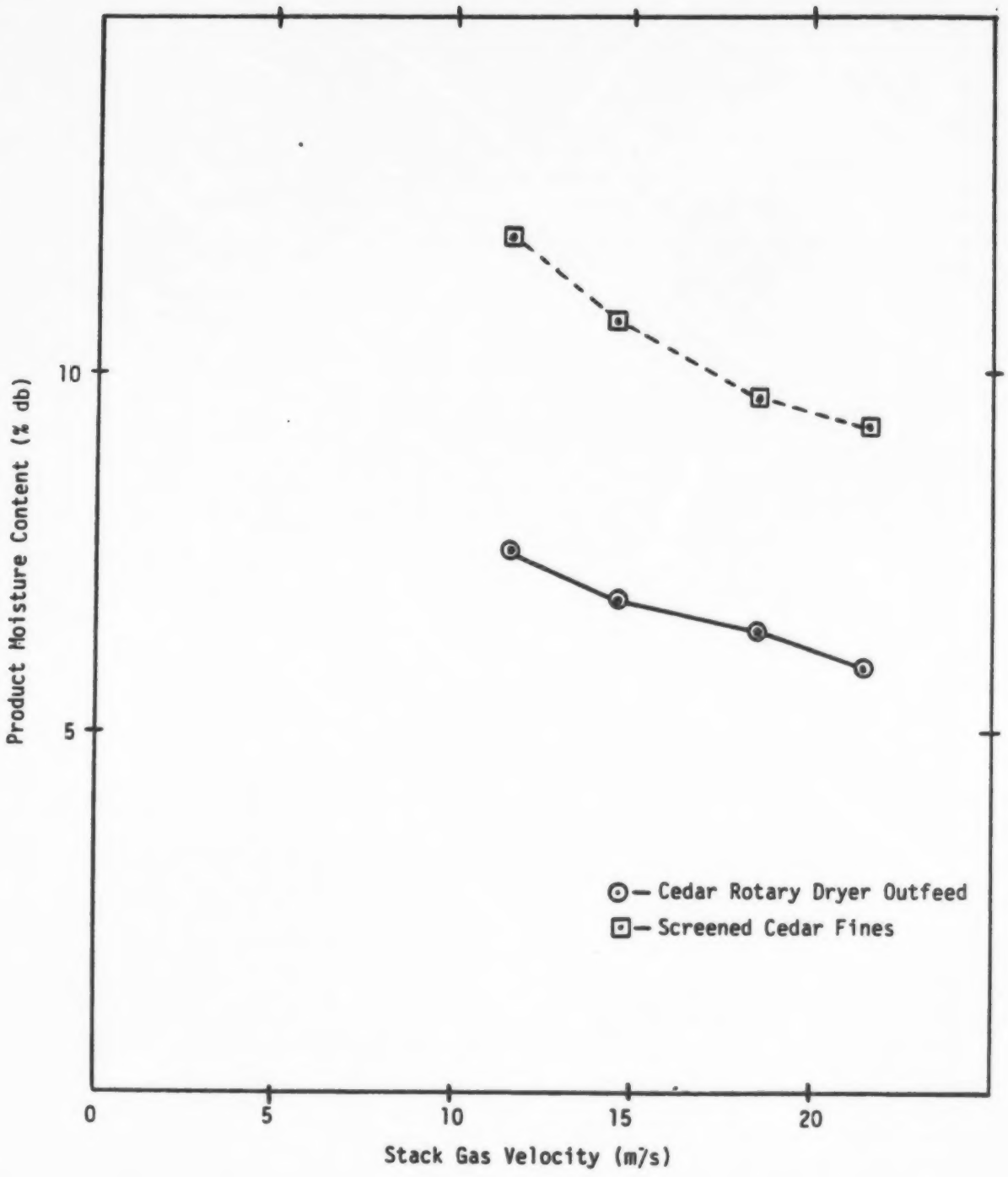


FIGURE 33: Variation of Flash Dryer Product with Stack Gas Velocity

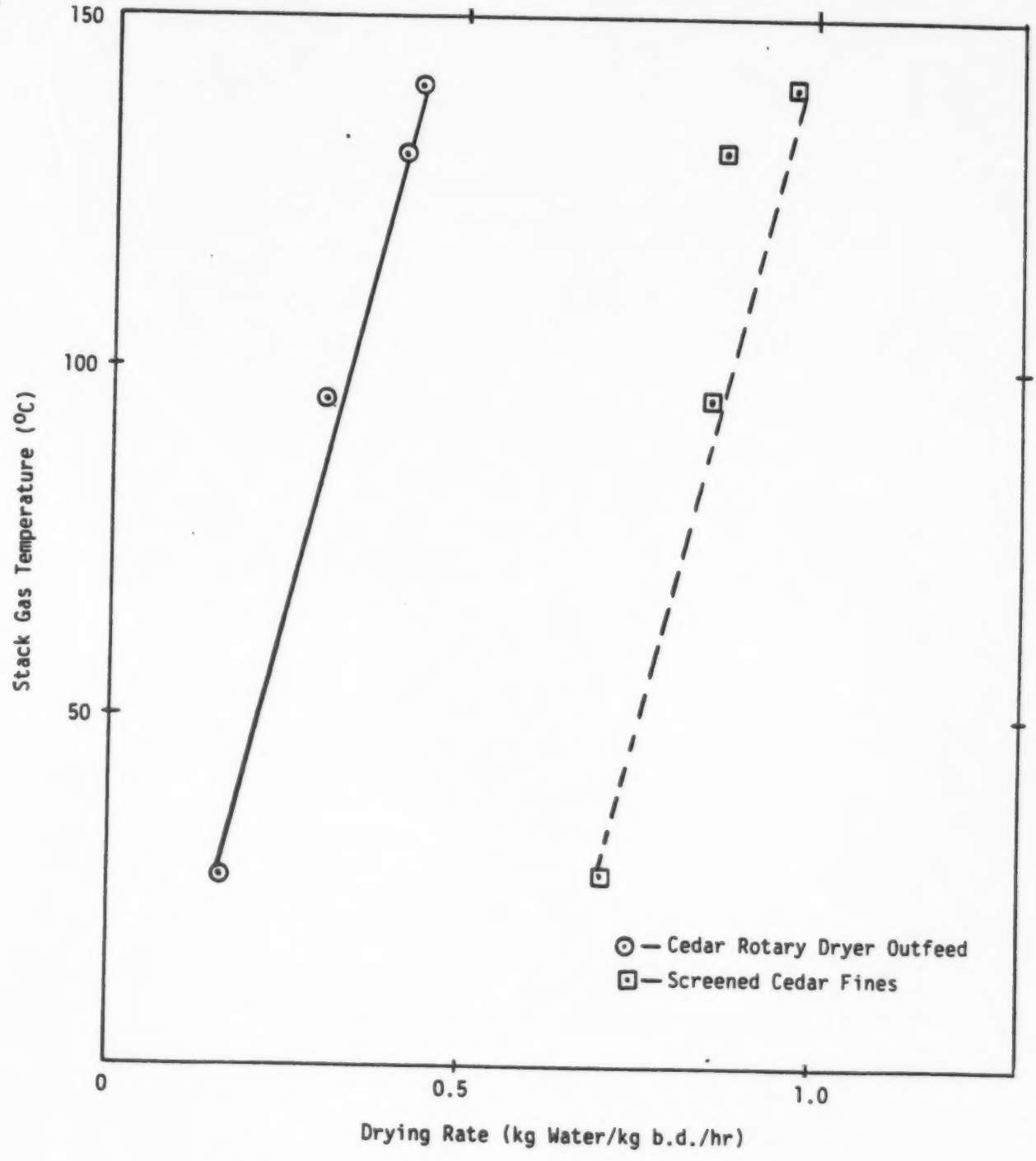


FIGURE 34: Variation of Drying Rate with Stack Gas Temperature

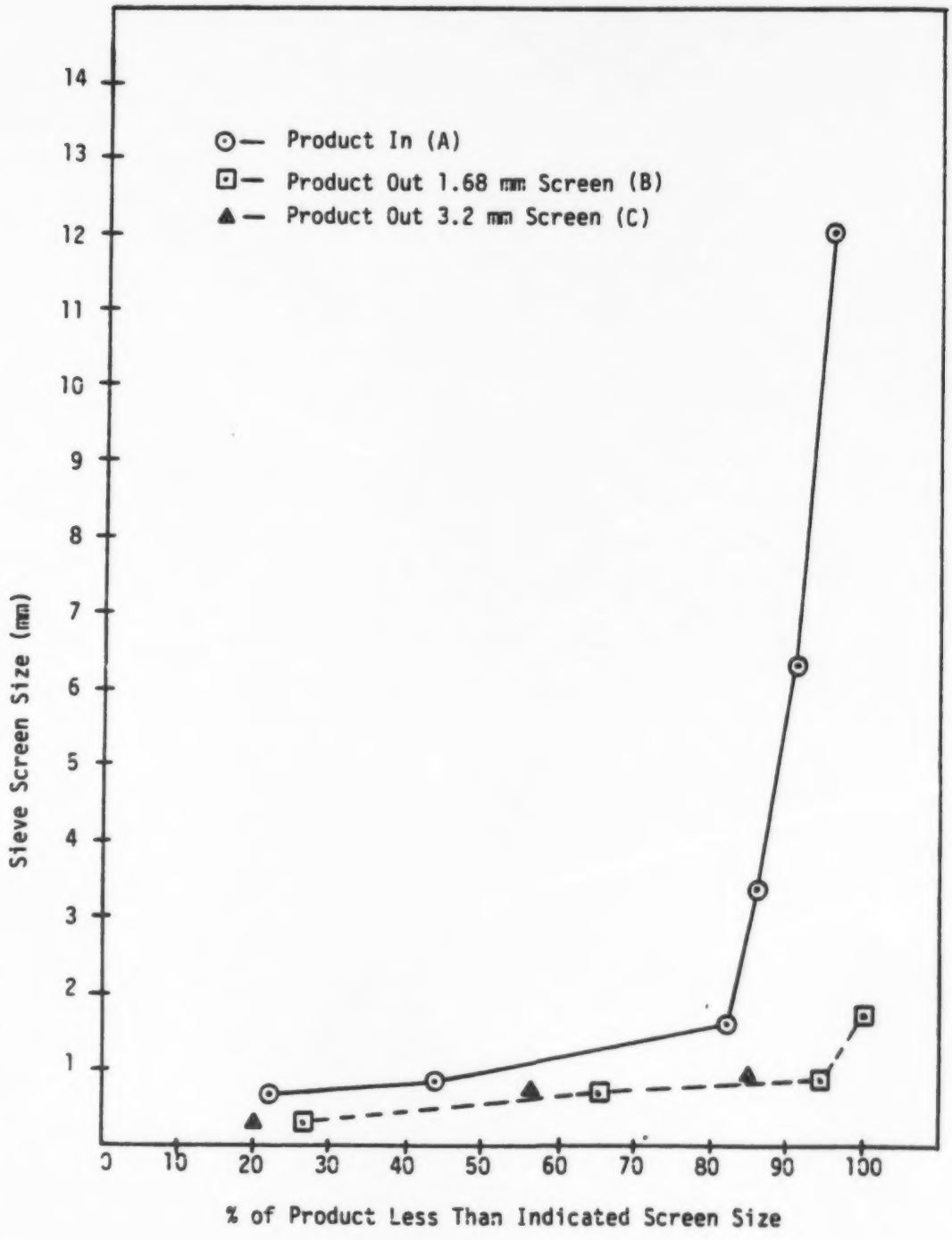


FIGURE 35: Pulverizing Record for C.W.P. Cyclone Catch

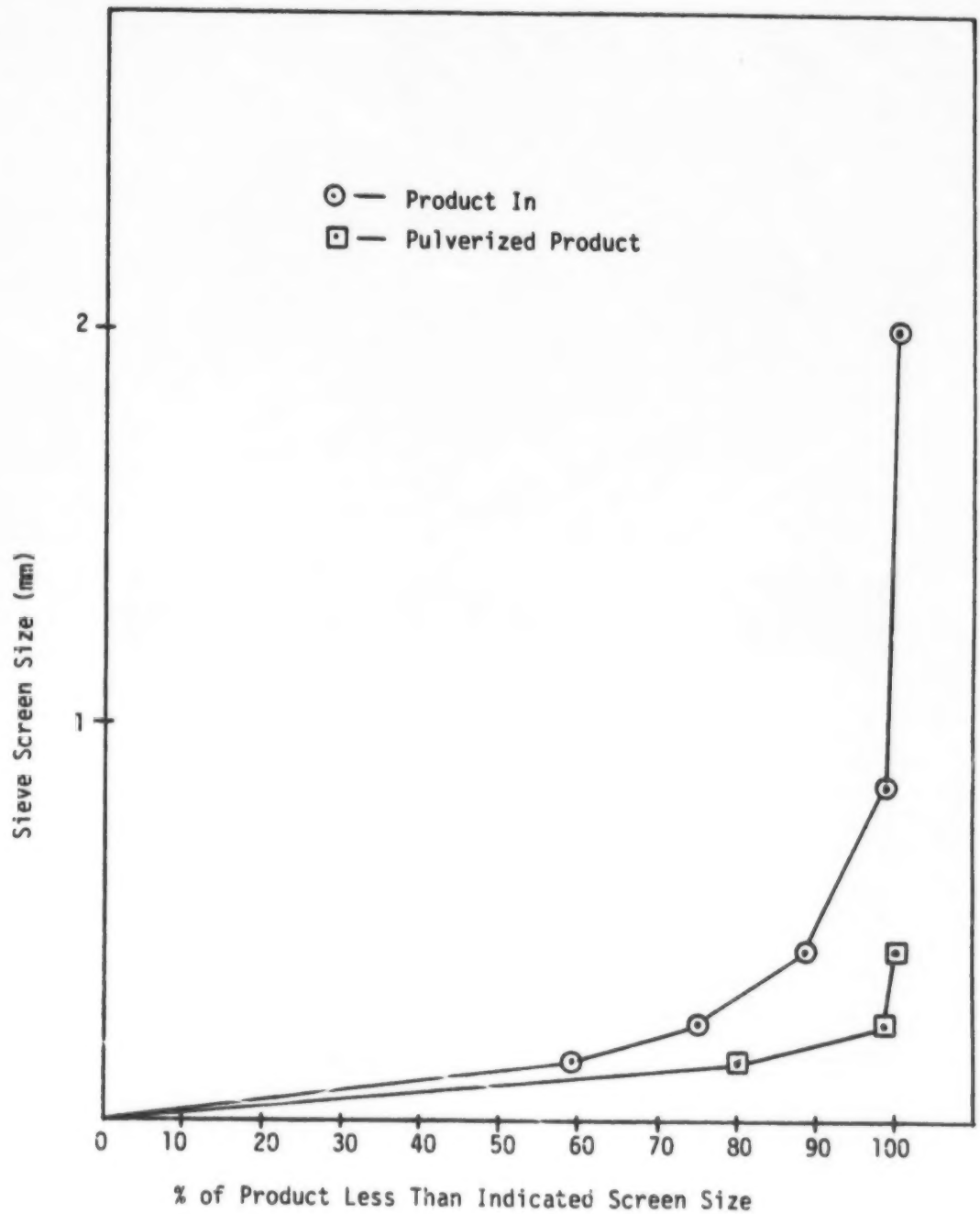
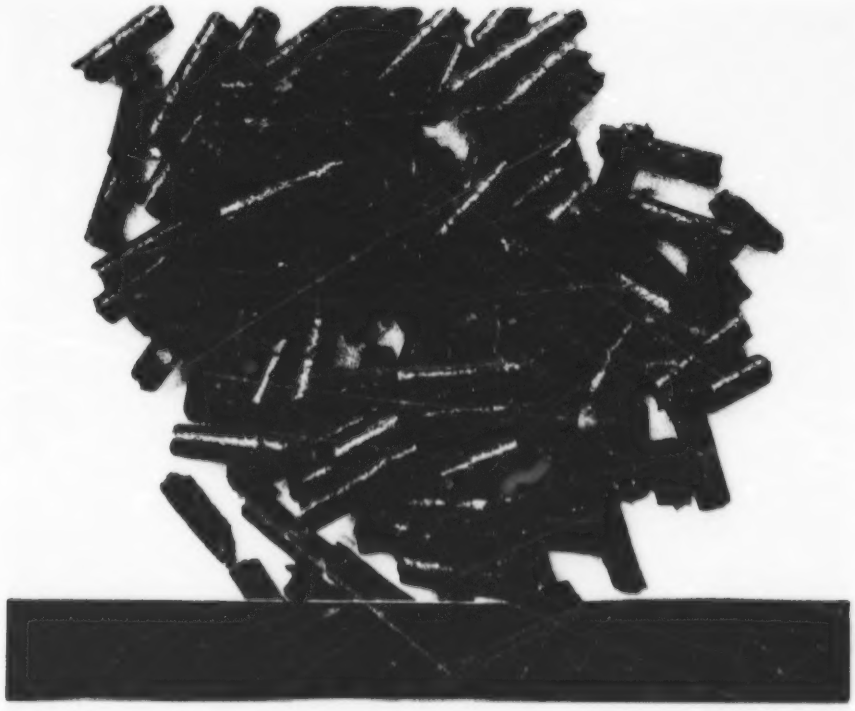
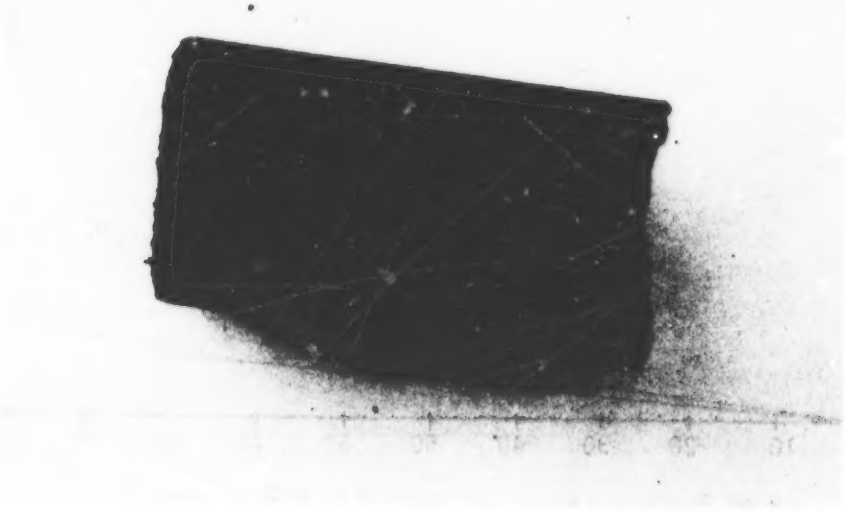


FIGURE 36: Pulverizing Record for Wood Fines



Cedar
Pellets

inches
centimeters



Cedar
Briquette

FIGURE 37: Samples of Densified Wood

This report has been produced through an ENFOR contract

Ce rapport a été produit via un contrat ENFOR